Systems Engineering

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FAME In-Process Systems Engineering

- Establish Systems Engineering and Integration Team
  - Lead Scientists and Engineers for Each Subsystem, Science Team Chair, Project Scientist, System Engineering Advisors
- SEIT Identifies, Integrates and Validates Requirements
- SEIT Tracks Performance/cost Metrics: Mass, Power, RF Margin, CPU Usage
- Protects Management's Cost, Technical and Schedule Goals

FAME SEIT
Systems Engineering and Integration Team

Mr. J. Hauser
Systems Engineer

Dr. K Johnston
Principal Investigator

Mr. M Johnson
Program Manager

Dr. R Vassar
Instrument Manager

Dr. D. Monet
Project Scientist

Dr. S. Horner
Instrument Systems Engineer

Mr. G. Flach
Systems Engineer

Technical, Cost Schedule GOALS

Mr. R. Mader
S/C Bus Mechanical Lead

Dr. P.K Seidelmann
Science Team Chair

Dr. R. Gaume
MO&DA
Lead

Mr. C. Garner
S/C Bus Electrical Lead

Dr. J. Phillips
SAO
Advisor

Ms. P. Klein
Ground Systems

Dr. M .Corson
Optics
Advisor

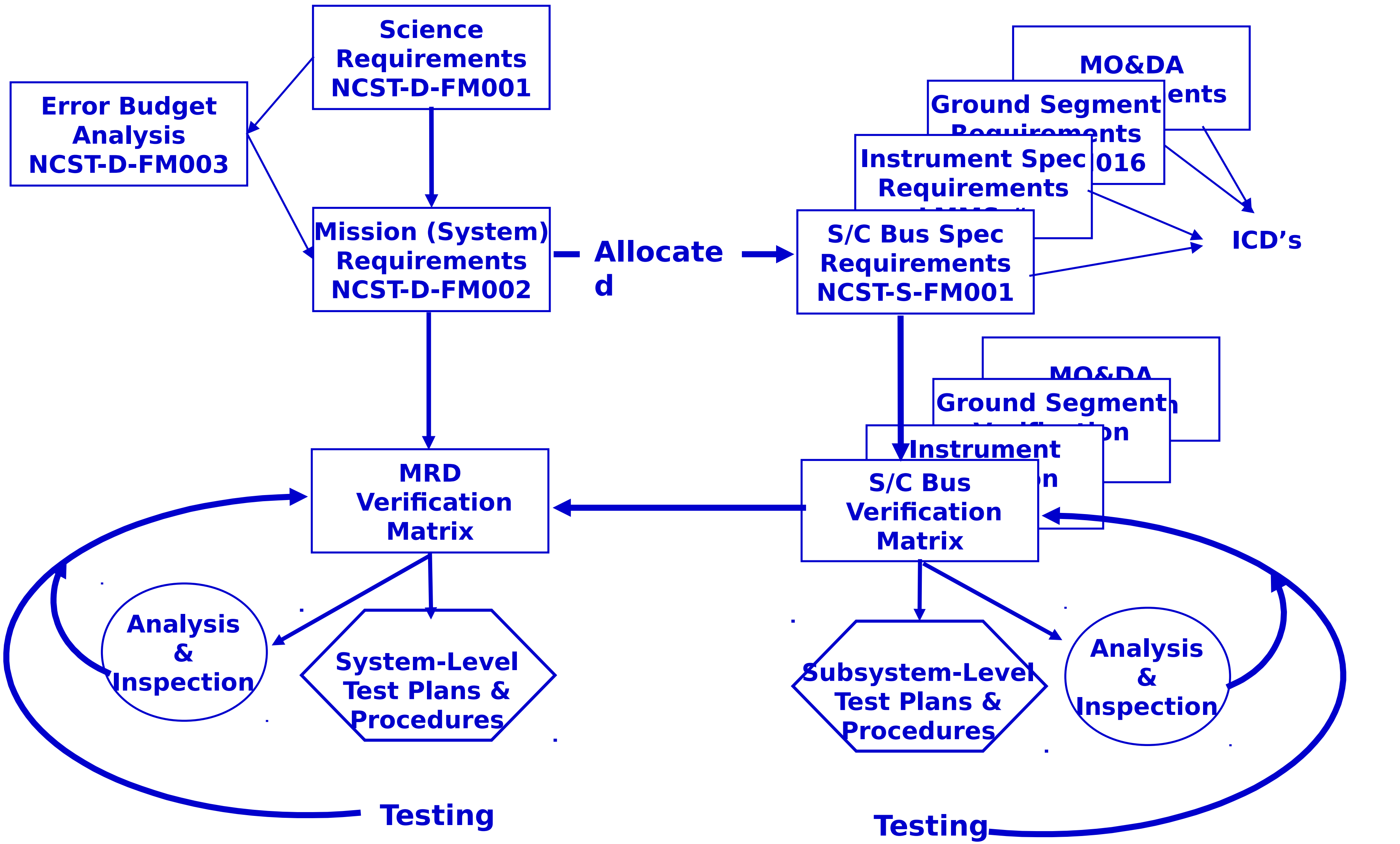
Systems Engineering Insight

- SEIT Team Horizontal Structure Provides Insight to All Project Aspects
- Communication Between Team Members Facilitated By:
  - FAME USNO Website
    - Provides Access to Technical Memo's, Documents (Released and Drafts), Referenced Documents, Meeting Presentations, Design Review Material
  - Weekly SEIT Teleconference (NRL, USNO, LMMS, Others)
  - Technical Interchange Meetings
    - Every Six Weeks, Alternates Between NRL and LMMS
  - Module Reviews
    - Prior to Breadboard Electronics, Review Requirements Allocation, Conceptual Design
  - Peer Reviews
    - SEIT and Outside "Experts" Review Subsystem Design in Detail
  - Subcontractor Design Reviews
    - For Major Procurements; CCD's, Optics, Bus Components
  - Formal Design Reviews
    - Systems Requirements Review December 2000
    - Instrument Preliminary Design Review May 2001
    - Preliminary Design Review October 2001

Peer Review Summary

- **Electrical Power Subsystem**
  - **10/10/01** **Dr. George Dakermanji APL, Ms. Karen Stewart, Mr. Joe Bolek GSFC**
- **Flight Software**
  - **5/14-17/01** **Mr. D. Oswald, J. VanGaasbeck, E. Andrews**
  - **10/16/01** **IVV Mr. Madhu. Rao, Paul Kirsch, Jack Abraham SAIC**
- **CTDH**
  - **10/16/01** **Mr. John Ruffa, Joe Bolek GSFC, Mr. Tim Meehan, Mr. G.Flach Mr. Noel Elliot NRL, Mrs. Amy Hurley NRL**
- **Radio Frequency**
  - **10/12/01** **Mr. Gil Herlich NRL, Mr. Paul Morth APL, Mr. Adan Rodriquez GSFC**
- **ADCS**
  - **10/12/01** **Mr. Martin Houghton, Joe Bolek GSFC, Mr. Wayne Dellinger, Ms. Robin Vaughn, JHU/APL**
- **Thermal Control Subsystem**
  - **10/12/01** **Dr. Wes Ousley GSFC, Mr. George Flach, Mr. Russ Barnes NRL**
- **Mechanisms**
  - **10/11/01** **Mr. Ed Devine Swales, Mr. Roger Farley, Mr. Joe Bolek GSFC, Mr. Russ Barnes, Mr. Bill Purdy NRL**
- **Structures**
  - **10/10/01** **Mr. Ted Sholar, Steve Vernon APL, Roger Farley GSFC**
- **Reaction Control Subsystem**
  - **10/10/01** **Mr. Gary Davis, Joe Bolek GSFC, Dr. Larry Mosher APL, Mr. R. Wojnar NRL**

Requirements Allocation & Verification



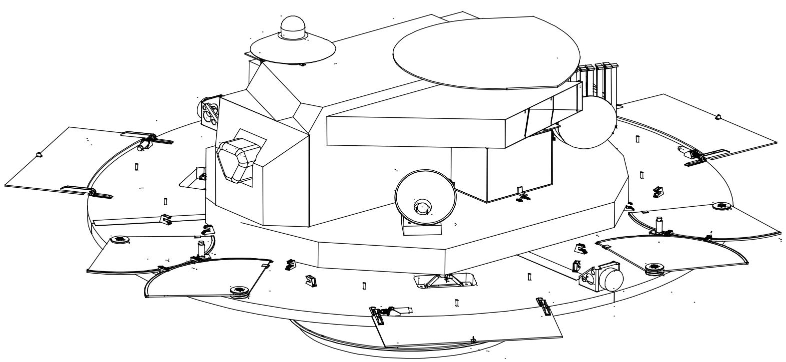
FAME Requirements Allocation

Mission
- Near GEO Orbit
- 5 Year Life
- Radiation: 18 krad Total Dose

Science
- Position, Proper Motion,Parallaxes Of 40 Million Stars
- Accuracy of 50 µAs @ 9th vismag
- Accuracy of 500µAs @ 15th vismag

Flight SW
- Resource Management
- Science/Engineering Data Collection
- Guidance Navigation & Control
- Attitude Determination
- FDIR

Mechanical
- Shade the Instrument
- 7425-10 Launch Loads, 10 ft. Fairing
- Sun Shield Flatness
- Spin Axis Alignment
- Long Term Stability



Instrument
- Dual Aperature Telescope
- CCD Array Using TDI
- Basic Angle Stability

Thermal
- FPA < 90˚C
- Electronics 0 - 50˚C
- Instrument Interface 0 - 40˚C
- MLI Flatness 0.25” Over

ADCS& RCS
- Spin Period 40 +/-4 min
- Sun Angle 35 +/- 5 deg
- Precession of Spin Axis Using Solar Pressure
- Cross Scan Accuracy
- In Scan Accuracy

Radio
- 2kbps Uplink
- 500kbps Downlink
- CCSDS
- 1 kbps Emergency Downlink
- STDN/NRL Compatible

MODA
- Operate FAME On Orbit
- Real-Time, and Stored Commanding
- Telemetry Display
- Archive Data
- Analyze & Reduce Data
- Produce Star Catalogs

EPOS
- 500W EOL
- Energy Storage
- Power Distribution
- Ordnance Control

CT&DH
- Execute, Store Commands
- Provide Telemetry
- Provide Science Data Buffer
- Instrument Control
- Star Catalog

System Trade Studies Performed

Trade	Options	Status	Result
Sun Angle	35°, 45°, 50°	Closed	35±5°
Precession Backup	Torque Rods, Thrusters	Closed	Torque rods
Measurement of Bright Stars	Filters, Start/Stop Tech.	Open	
Orbit	Geostationary vs GeoSync Drifting	Closed	105º W, Drifting Eccentric Orbit
Solar Array/Sun Shield	Single vs Multiple Hinges	Closed	OBE-Descope Fixed Solar Array
Data Rates (Function of Science Data)	RF Output/Ground ANT Characteristics	Closed	500 kbps,13 m Antenna
Ground Station Location	BP, DSN, Others	Closed	BP Primary Augmented by DSN
AKM Hole	Leave Open or Cover	Closed	OBE-Descope, No Hole In Descope Design

System Performance Metrics

Performance Metrics Tracking

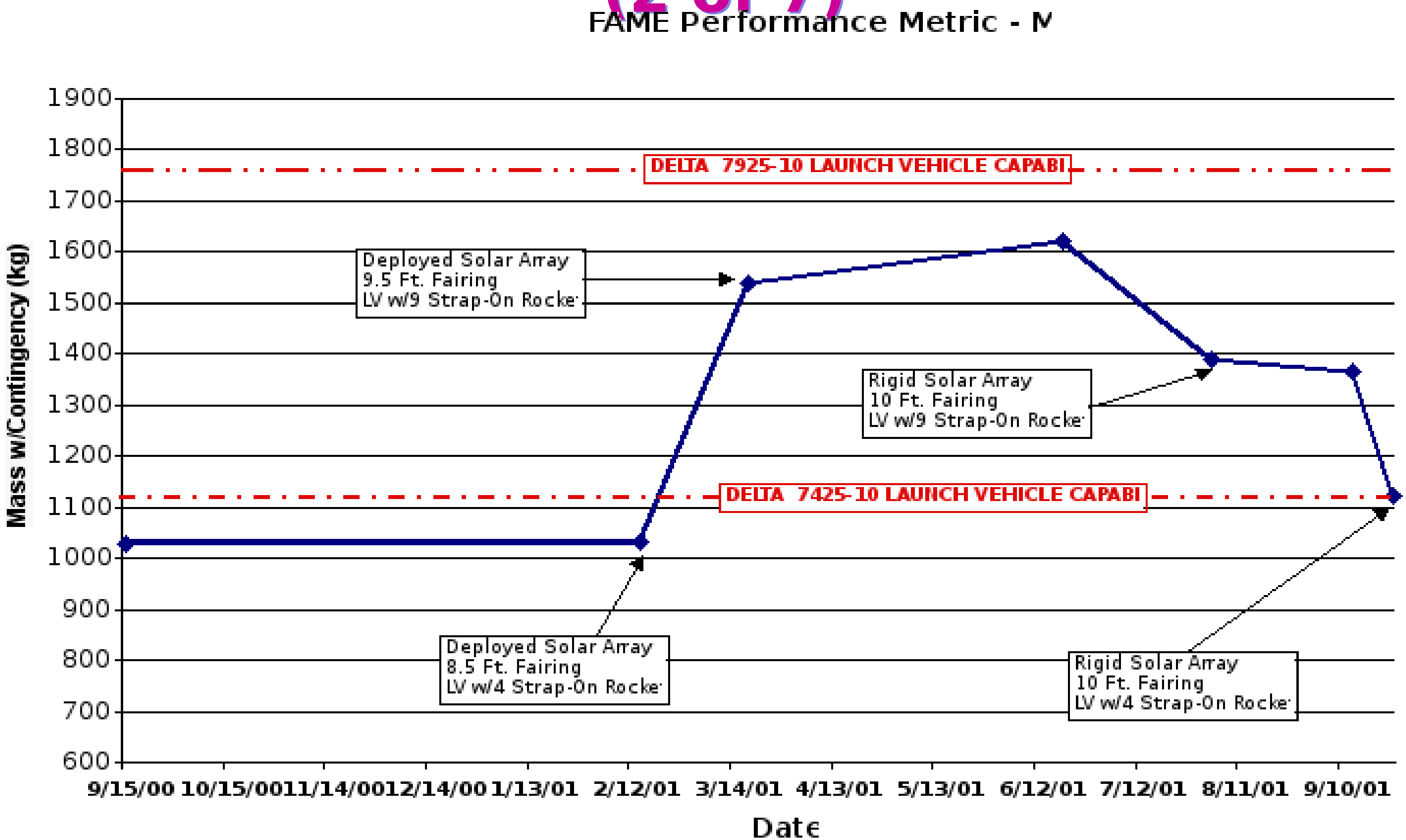
- **Performance Metric Budgets Tracked By Systems Engineering**

Metric	How Tracked	Responsible	Update Frequency
– Mass	Excel Spreadsheet	Ron Mader	Daily, Weekly
– Power	Excel Spreadsheet	Chris Garner	As Required
– CPU	Excel Spreadsheet	Ray Caperoon	As Required
– RF	Excel Spreadsheets	Ed Becker	As Required

PDR Performance Metrics (1 of 7)

- **Mass**
  - **Margins**
    - **Uncertainty in Estimates (Held at Subsystem Level)**
    - **25% Added to Propellants, 20% on New Designs, 10% on Design Mods, 5% on Off-the-shelf Hardware**
  - **Reserve**
    - **LV Throw Weight Less Mass Est. With Uncertainty (Held at System Level)**
    - **20% of Observatory Mass (Less Apogee Kick Motor) Desired**

PDR Performance Metrics - Mass (2 of 7)



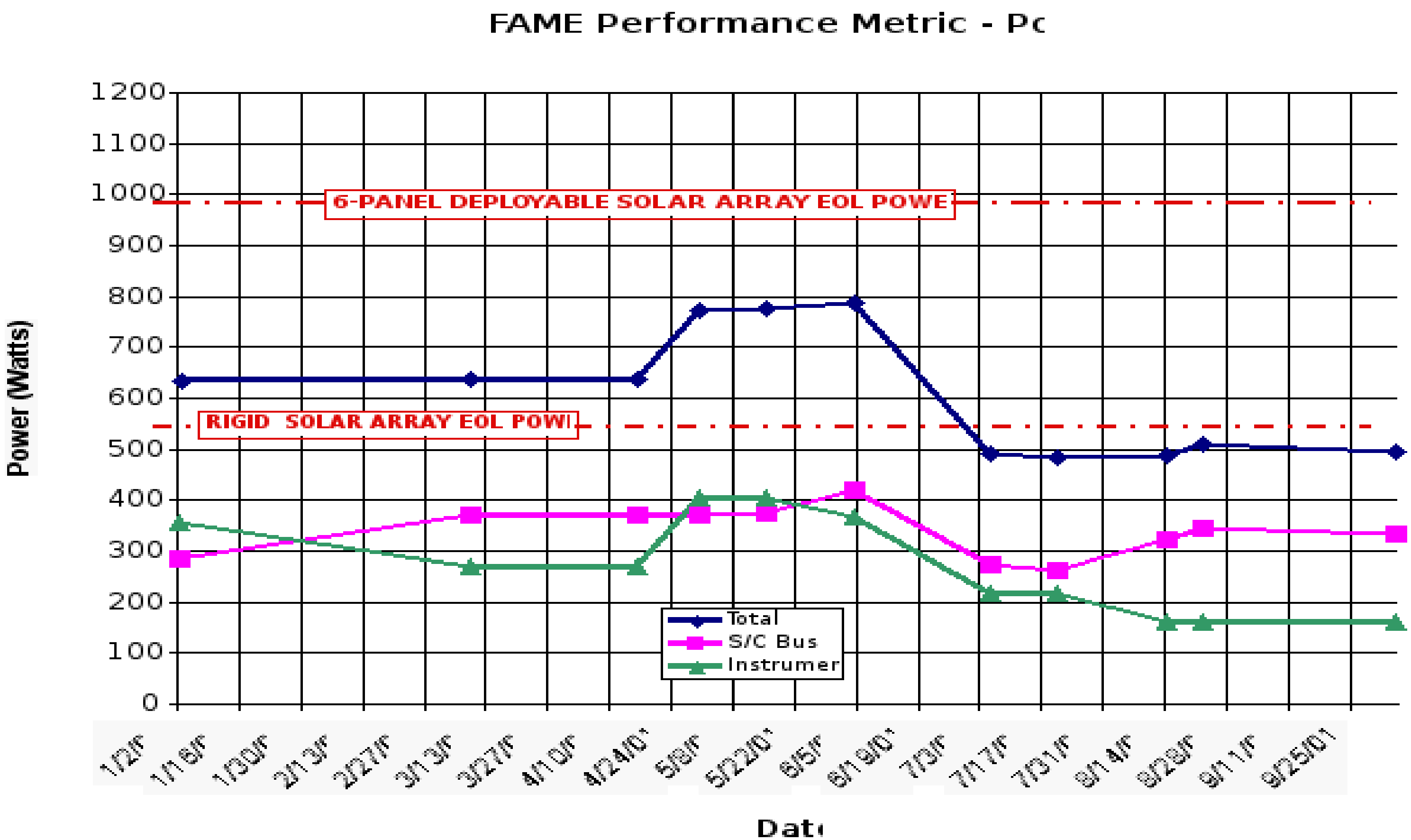
PDR Performance Metrics- Mass (3 of 7)

Subsystem/Component	Mass Estimate (Kg)	Uncertainty (Kg)	Mass W/Uncertainty (Kg)	Uncertainty (%)
Flight Vehicle	1038.76	85.09	1123.85	8.19%
Instrument Assembly	193.60	38.80	232.40	20.04%
Interstage Assembly	557.13	9.06	487.39	1.63%
S/C Bus	288.03	37.23	314.18	12.93%
GFE on Instrument	9.07	2.27	11.34	25.03%
S/C Mechanical	93.64	11.03	104.67	11.78%
S/C Bus RCS Dry	23.34	1.61	24.95	6.90%
S/C Bus RCS Propellant	39.92	9.98	49.90	25.00%
S/C Bus ADCS	9.18	0.46	9.64	4.99%
S/C Bus Mechanisms	21.21	1.96	23.17	9.24%
S/C Bus EPS	46.90	5.78	52.68	12.32%
S/C Bus RF	11.61	1.09	12.69	9.39%
S/C Bus CT&DH	18.28	1.58	19.86	8.64%
S/C Bus TCS	14.88	1.47	16.62	9.88%

Launch Vehicle Capability (7425-10)	1110.00	(Kg)
Mass Estimate	1038.76	(Kg)
Estimated Margin	71.24	(Kg)
Contingency Mass	85.09	(kg)
Reserve	-13.8	(kg)

PDR Performance Metrics- Power (4 of 7)

- **Power**
  - **Instrument Carries 20% Design Contingency**
  - **S/C Bus Carries 20% Design Contingency**



PDR Performance Metrics- Power (5 of 7)

- **Power Margins**
  - **+ Margin for All Mission Phases**
    - **(Peak Loads Are msec Duration and Will Be Supported by Battery)**

PDR Performance Metrics – RF Margins (7 of 7)

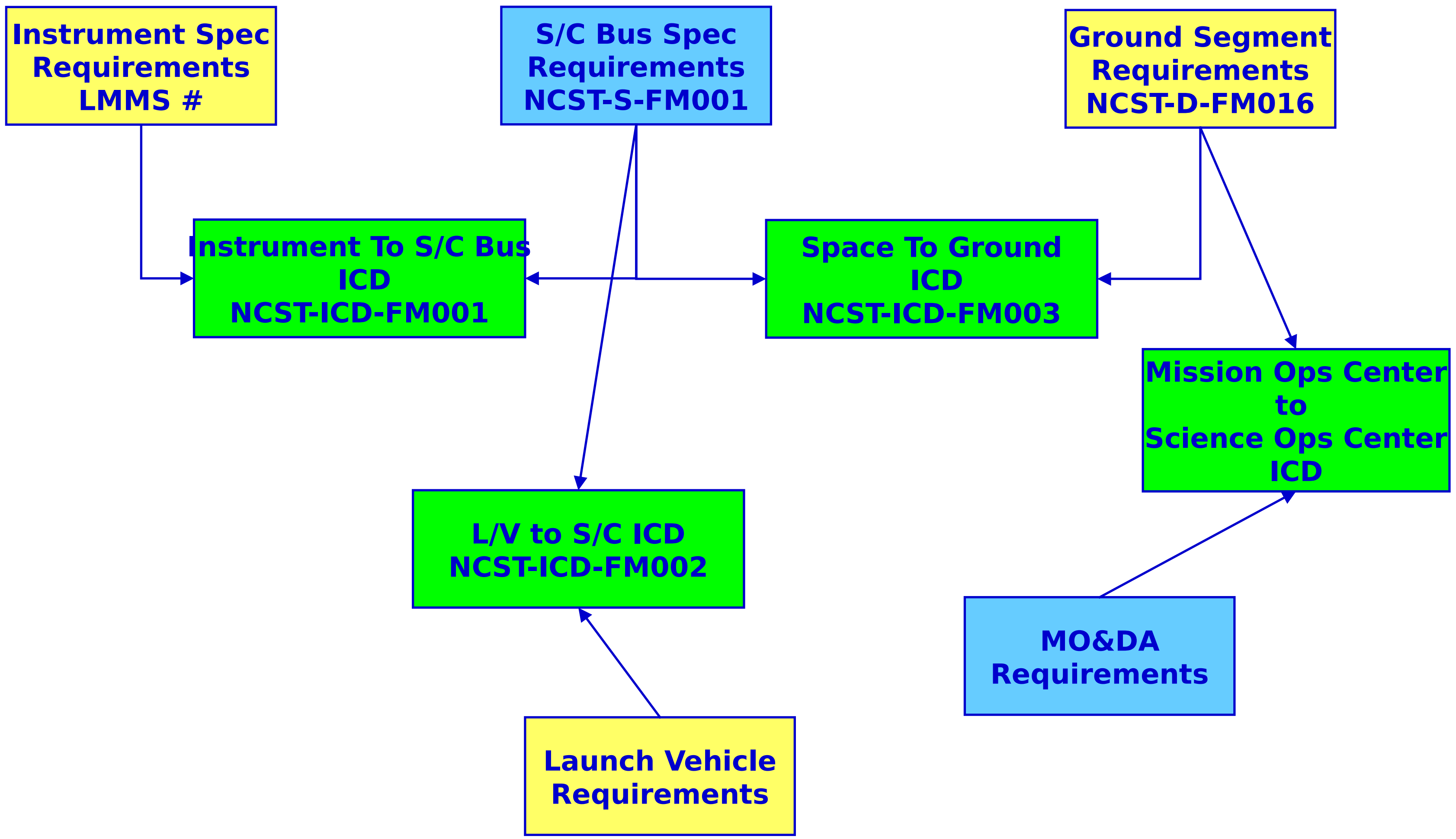
- **RF Link Budget**
  - **3 dB Margin on All Links Required**

LINK	DATA RATE (kbps)	ANTENNA	ORBIT	MARGIN (dB)
Uplink	2	Fore/Aft	GEO	10.6
Downlink	1	Side	GEO	13.6
Downlink	500	Fore/Aft	GEO	3.2
Downlink	250	Fore/Aft	GEO	2.5
Ranging		Fore/Aft	GEO	10.9

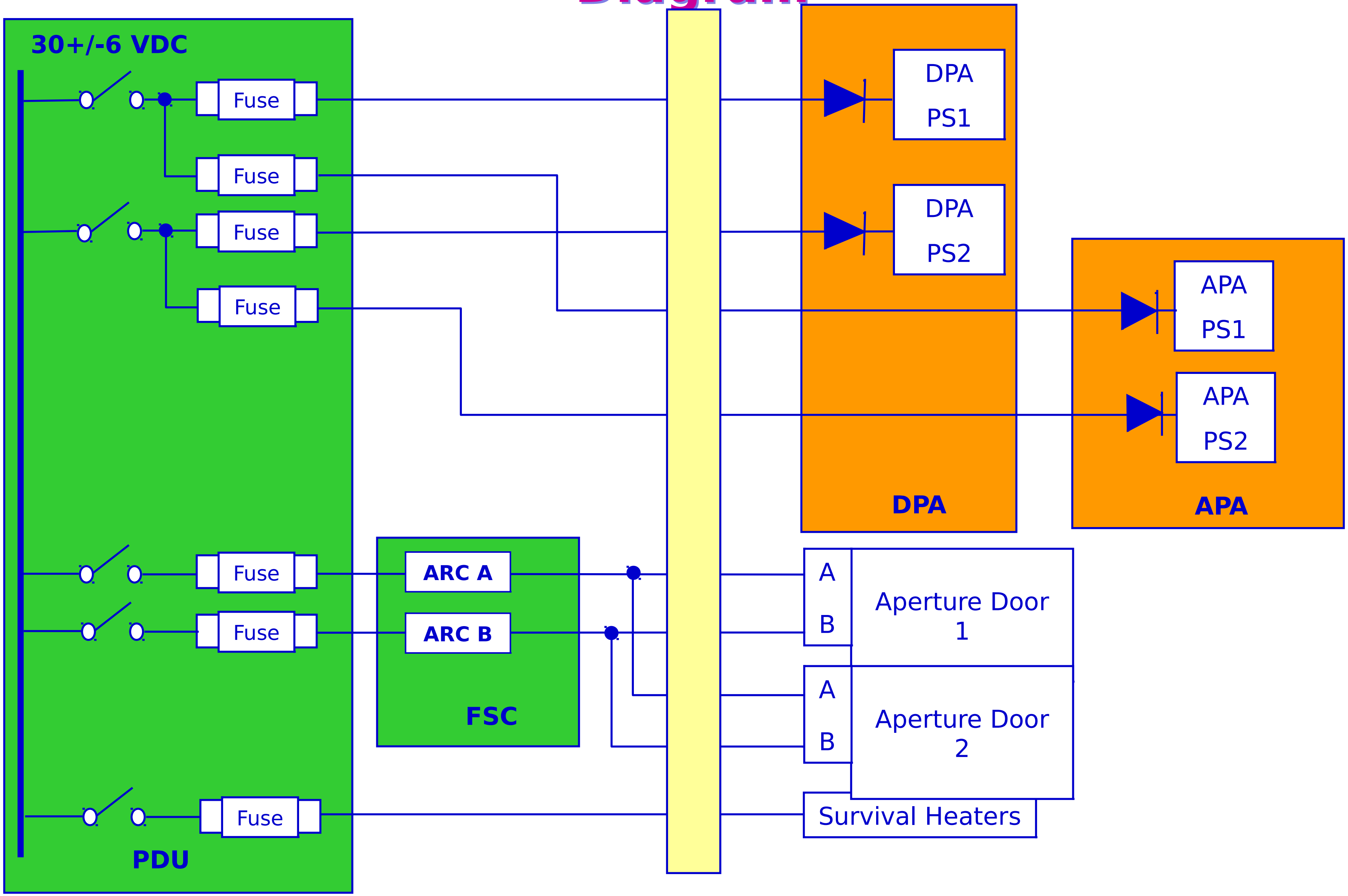
Note 1	Side Antenna Are Helix
Note 2	Fore/Aft Antenna Are Waveguide
Note 3	Occurs At Crossover Area Between Fore & Aft Antennas

Interface Identification

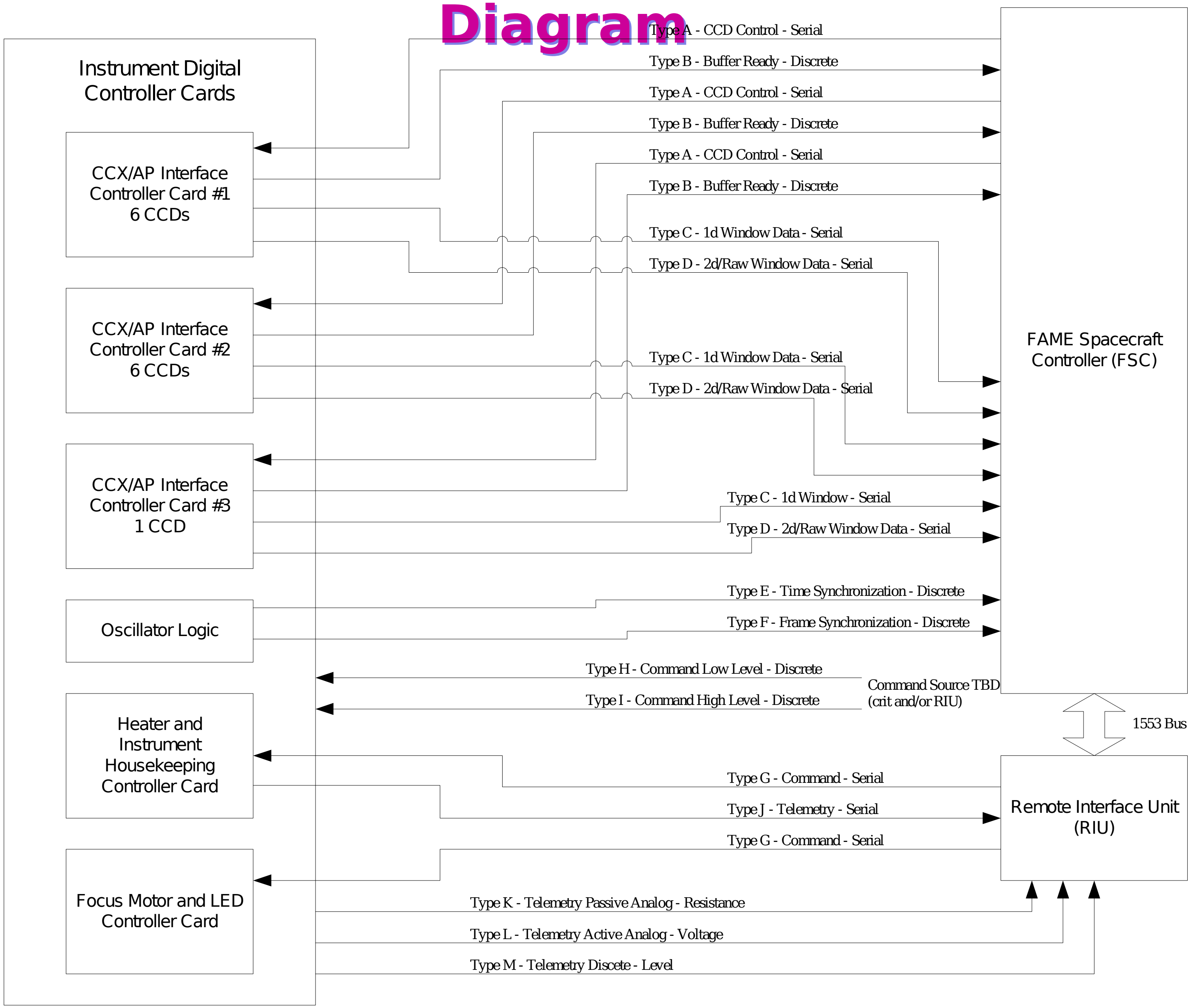
Interface Identification & Control



S/C Bus to Instrument Electrical Power Interface Block Diagram



S/C Bus to Instrument Electrical Control & Data Interface Block Diagram



S/C Bus to Instrument Interface Summary Interface Wire Count

From	To	Type	Wire Count
FSC - IF Card	CCX/AP IF Controller Card #1	A	6
CCX/AP IF Controller Card #1	FSC - IF Card	B	2
CCX/AP IF Controller Card #1	FSC - IF Card	C	8
CCX/AP IF Controller Card #1	FSC - IF Card	D	8
FSC - IF Card	CCX/AP IF Controller Card #2	A	6
CCX/AP IF Controller Card #2	FSC - IF Card	B	2
CCX/AP IF Controller Card #2	FSC - IF Card	C	8
CCX/AP IF Controller Card #2	FSC - IF Card	D	8
FSC - IF Card	CCX/AP IF Controller Card #3	A	6
CCX/AP IF Controller Card #3	FSC - IF Card	B	2
CCX/AP IF Controller Card #3	FSC - IF Card	C	8
CCX/AP IF Controller Card #3	FSC - IF Card	D	8
Oscillator Control Logic	FSC - IF Card	E	2
Oscillator Control Logic	FSC - IF Card	F	2
RIU (Serial)	Heater & Inst HK Controller Card	G	6
RIU and/or FSC Crit (TBD)	Instrument (exact destination TBD)	H	8
RIU and/or FSC Crit (TBD)	Instrument (exact destination TBD)	I	0
Heater & Inst HK Controller Card	RIU (Serial)	J	6
Instrument (exact source TBD)	RIU (Passive Analog)	K	24
Instrument (exact source TBD)	RIU (Active Analog)	L	4
Instrument (exact source TBD)	RIU (Discrete)	M	0
		Total	124

S/C Bus to Instrument Data/Control Interface Summary

Type	Name	Signal				Wire Count	Word Size (bits)	Clock Rate Hz
		1	2	3	4			
A	CCD Control	Clock	Data	Enable	-	6	33	12,500,000
B	Buffer_Ready	CTS	-	-	-	2	-	~0.50
C	CCD 1d Window Data	Clock	Data	Enable	Channel_Act	8	64	12,500,000
D	CCD 2d/Raw Window Data	Clock	Data	Enable	Channel_Act	8	64	12,500,000
E	Time_Synch_Epoch	Pulse	-	-	-	2	-	~0.10
F	Frame_Synch_Epoch	Pulse	-	-	-	2	-	4096 * row_interval
G	Commands Serial	Clock	Data	Enable	-	6	17	125,000
H	Commands Low Level	Pulse	-	-	-	n * 2	-	per signal
I	Commands High Level	Pulse	-	-	-	m * 2	-	per signal
J	Telemetry Serial	Clock	Data	Enable	-	6	16	125,000
K	Telemetry Passive Ana	Resistance	-	-	-	r * 2	-	per signal
L	Telemetry Active Ana	Voltage	-	-	-	s * 2	-	per signal
M	Telemetry Discretes	Level	-	-	-	t * 2	-	per signal

Notes:	Types A, C, D, G, J	At least one clock cycle is required between words (enables)
	Type A, C, D, G, J	Msbit first
	Type A	Odd Parity, Parity Bit is last bit transmitted per word
	Type B	Buffer Ready (clear to send) is active for the duration while the buffer is available for loading
	Type C	Channel Active will remain active on the binned data interface for the duration of a buffer download
	Type C	Channel Active will become active 300 micro-seconds (TBR) prior to transmission of binned data
	Type D	Channel Active will remain active on the unbinned/engineering data interface for the duration of each frame
	Type D	Channel Active will become active and envelope each frame with a minimum of TBD clock cycles between frames
	Type H	Defined Signals (n = 4): 1 - Instrument Reset A, 2 - Instrument Reset B,
		3 - Oscillator A select, 4 - Oscillator B Select
	Type I	Defined Signals (m = 0): TBD
	Type K	Defined Signals (r = 12): 1 to 12 - Instrument Assembly Temperatures
	Type L	Defined Signals (s = 2): 1 - +5V monitor A, 2 - +5V monitor B
	Type M	Defined Signals (t = 0): TBD

Observatory to Launch Vehicle Electrical Interface Summary

- **T-0 Umbilical**
  - **Power**
  - **Data**

- **Loopback for Separation Confirmation**

S/C Bus to Instrument Mechanical Interface Summary

- Spacecraft Bus to Instrument (NCST-ICD-FM001)
  - Observatory Coordinate System
  - Mechanical Interface Drawing (FM-IC-0005)
    - Instrument Envelope
    - Instrument Fields of View
    - Star Tracker and Antenna Fields of View
    - Instrument to Spacecraft Bus Mounting
    - Star Tracker and Antenna Mounting Interface
  - Instrument Mass Allocation
  - Instrument Center of Mass Requirements (Long/Lateral)
  - Instrument Moments & Products of Intertia
  - Instrument to S/C Bus Mounting Hardware
  - Alignment Accuracies, Responsibilities
  - Reference Structural Design Requirements

S/C Bus to Instrument Mechanical Interface Summary

- S/C Bus to Instrument Thermal Interfaces
  - Surface Optical Properties
  - Nominal Operating Temperature Ranges
  - Short Term Thermal Stability Without Eclipse
  - Thermal Stability Including Eclipse
- Conduction Between S/C Bus and Instrument
- Temperature of Instrument At Interface
- Temperature of S/C Bus At Interface
- Star Tracker/Antenna Thermal Interfaces

Observatory to Launch Vehicle Mechanical Interface Summary

- **Delta 7425-10 Launch Vehicle Fairing Envelope**

- **Delta 7425-10 Payload Adapter Interface**

Protoflight Box Test Flow

- Ambient Thermal Cycle & Test
- EMI (If Required)
- Ambient Thermal Cycle & Test
- Conformal Coat & Stake Boards
- Start Acceptance Test Program
- Ambient & Thermal Cycle Tests
- 3 Axis Random Vibration
- Ambient Tests
- Thermal Vacuum Or Thermal Cycles
- Ambient Test
- Complete Burn-In
- Buyoff
- Delivery For System Integration

System Test Outline

- Protoflight Observatory & Flight Vehicle
  - Vibro-Acoustic Testing (Flight +3dB for 1 min/axis)
  - Thermal Vacuum
  - Magnetic Balance
  - EMI/EMC
  - Spin Balance/Mass Properties
  - Pyroshock
  - Electrical Functional & Performance Tests
  - Sensor Alignment (Pre-Test, Post Vibro-Acoustic, Post TVAC)
  - Released Test Procedures
    - Test Sequence, Test Levels & Tolerances
    - Test Article & Test Facility Configuration
    - Responsibilities

Verification Program

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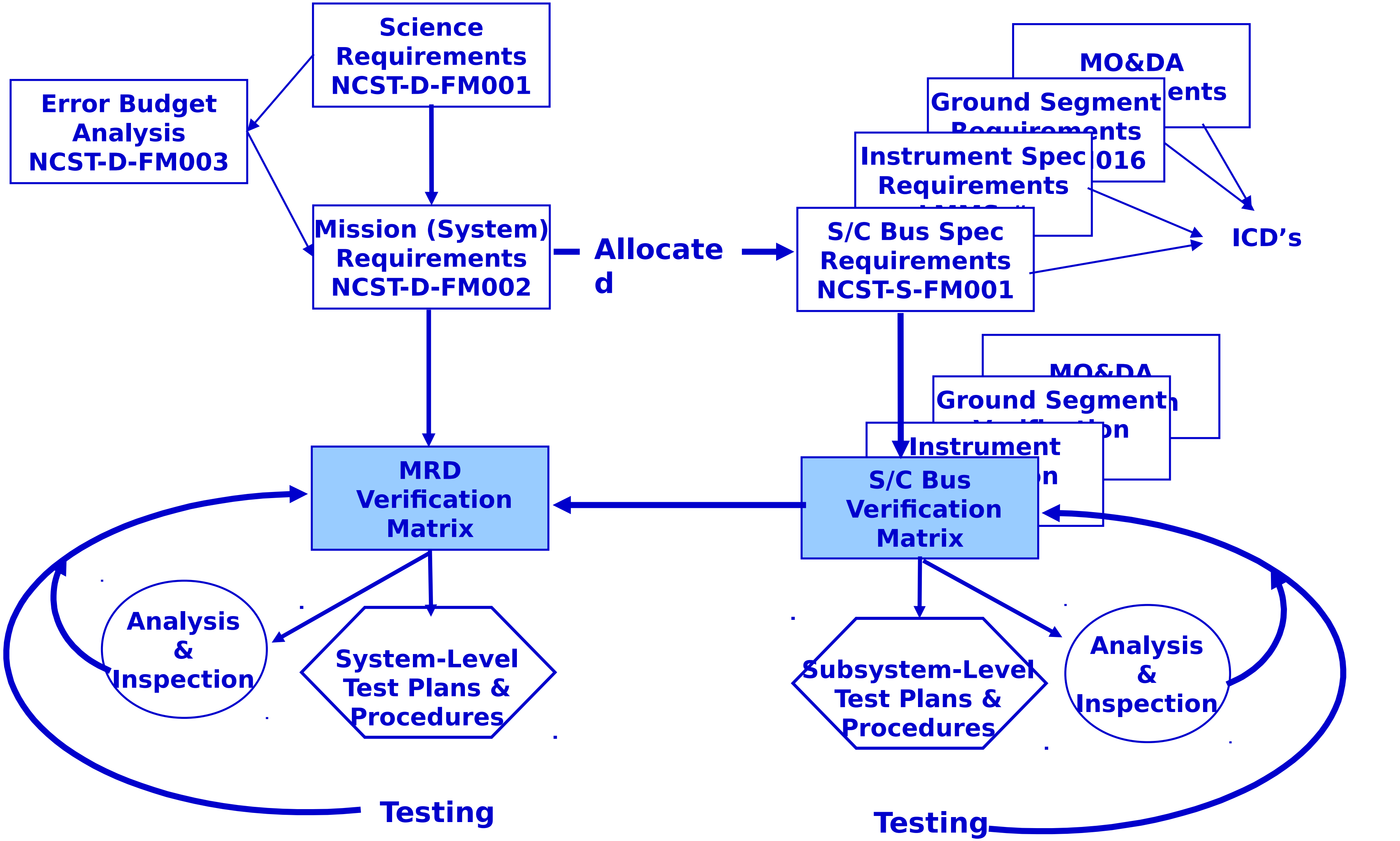
Requirements Allocation & Verification



FAME Requirements Verification-Verification Matrices

- Goal Is to Assure That Observatory Hardware and Software Will Perform The Required Mission
- To Achieve Goal:
  - Established Complete Set of Performance, Design, Interface and Safety Requirements
  - Verification Matrices
    - Establish Traceability From Requirements Documents to Design Implementation
    - Identify Methods to Verify Each Requirement
  - Individual Observatory Subsystems Responsible for Performing Verification and Documenting Evidence That Boxes/Subsystems Comply With Subsystem Requirements Document
  - Systems Engineering Performs Verification and Documents Evidence That the Observatory Design Complies With Mission Requirements Document

FAME Requirements Verification - Buyoff Procedure

- Utilize NRL Buy-Off Procedure to Support Verification
  - Buyoff Is A Formal Processs For Reviewing, At Pre-Defined Phases, The Work Performed Which Demonstrates Compliance and Establishes Requirements Traceability
    - Performed for Each Box/Subsystem Component And At Selected System Assembly Milestones
    - Ensures All Related Engineering Drawings Have Been Released
    - Verifies H/W Built and Tested to Approved Engineering Requirements
    - Verifies That All Discrepancies, Anomalies, and Non-conformances Have Been Documented and Dispositioned
    - Summarizes Verifications Completed to Level Of Buyoff
  - Copy of Buyoff Package Is Maintained by QA (TBR) to Support Verification and Future Inquiries

Verification Plan

- Verification Methods
  - Analysis
  - Inspection
  - Demonstration or Measurement
  - Simulation
  - Test

- Specific Tests, Analyses, and Inspections Are Presented In Subsystem, System Test Presentations

FAME Requirements Verification - Flight Software IV&V

- Conduct Peer Reviews
  - Selected Peer Review of Detailed Design & Unit Code
  - Level of Effort Set at 3 Hours Per Week Per Team Member
- NASA/IV&V Effort Is in Its Initial Phase
  - IV&V Is Working With the FSW Team and Reviewing Documentation
  - Project Plan Being Worked
  - Long Term Memorandum of Agreement Is Being Worked
- Conduct Independent Reviews
  - NRL Internal Review Performed 5/2001 by Non-Fame Contractors With Spacecraft SW Domain Expertise
  - Covered Development Approach, SW Re-Use Strategies, Design Issues and Test Approach
- FAME FSW Intermediate Design Review
  - FSW Team Is Planning a Program Supported Intermediate Design Review Focused on the FSW Development Approach, Requirements Baseline, Preliminary Design, Test Approach and Processor Throughput Analysis Results

System Issues/Concerns Summary

Issue	Description	Possible Solutions
Mass Margins	• Current Mass Reserves Not Acceptable • Potential for Mass Growth	• Weight Savings • Descopes • Different Launch Vehicle
Inertia Properties	• Tight Requirements for Transverse Moments of Inertia • Tight Requirements for Products of Inertia	• Large Balance Masses • Additional Trim Masses
Optical Properties	• Not All Parameters of Surfaces Available • Degradation Properties Unknown (Uniformity)	• Continue Test Program • Size Trim Tabs to Accommodate Worst Case Conditions
Error Budget	• Ability to Meet All Requirements • Some Requirements Verified by Analysis Only	• May Need to Relax/Trade Error Budget Requirements
Optical Thermal Stability	• Time Constant/Stability of Optical System	• Analysis/Modeling of Error Sources

System Issues/Concerns Summary

- **Mass Margins Inadequate**
- **Power Margins Positive**
- **RF Margins Good**
- **Processor Margins ?**

System Reliability

FAME Reliability Approach

- Maximize Science Return for Given Cost And Schedule
- Selective Subsystem Redundancy to Insure 5 Year Mission
  - Select Subsystems Single String Where Experience Is Low Risk
- Perform Reliability Analyses to Identify “Mission Ending” Effects
  - Adjust Designs Where Possible to Shift Effect From “Mission Ending” to “Degraded Mission”
- Test At Box, Subsystem and System Level
- Strive to Identify and Strengthen “Weak Links” to Mission Success

Reliability Requirements/Analysis

- Original Requirements for Reliability Analyses:
  - Reliability Prediction
    - Reliability Model Included in Charts
      - Reliability Is Estimated With Preliminary Card/parts Count Method, Heritage Hardware
  - Failure Modes and Effects Analysis (FMEA) At S/C Bus to Instrument Interface
  - Worst Case Analysis (Informal)
      - To Be Performed As Schematic Drawings Are Generated
- NASA Subsequent Request to Included The Following Analyses
  - Fault Tree Analysis
  - FMEA At Critical Interfaces
  - Probabilistic Risk Assessment

Reliability Analysis Flow

FAME Reliability Block Diagram

ADCS $R_1 = 0.95941$ — RCS $R_2 = 0.98990$ — Interstage $R_3 = 0.98000$ — CT&DH and RIU $R_4 = 0.97602$ — EPS $R_5 = 0.89190$ —

Mechanisms $R_6 = 0.99213$ — Thermal $R_7 = 0.99999$ — RF $R_8 = 0.99385$ — Instrument $R_9 = 0.85884$

MATHEMATICAL MODEL LEGEND

R_{FAME} = Reliability of the FAME Spacecraft for 5 Year (43,800 hour) mission.

R_i = Reliability of the i^{th} FAME subsystem

MATHEMATICAL MODEL

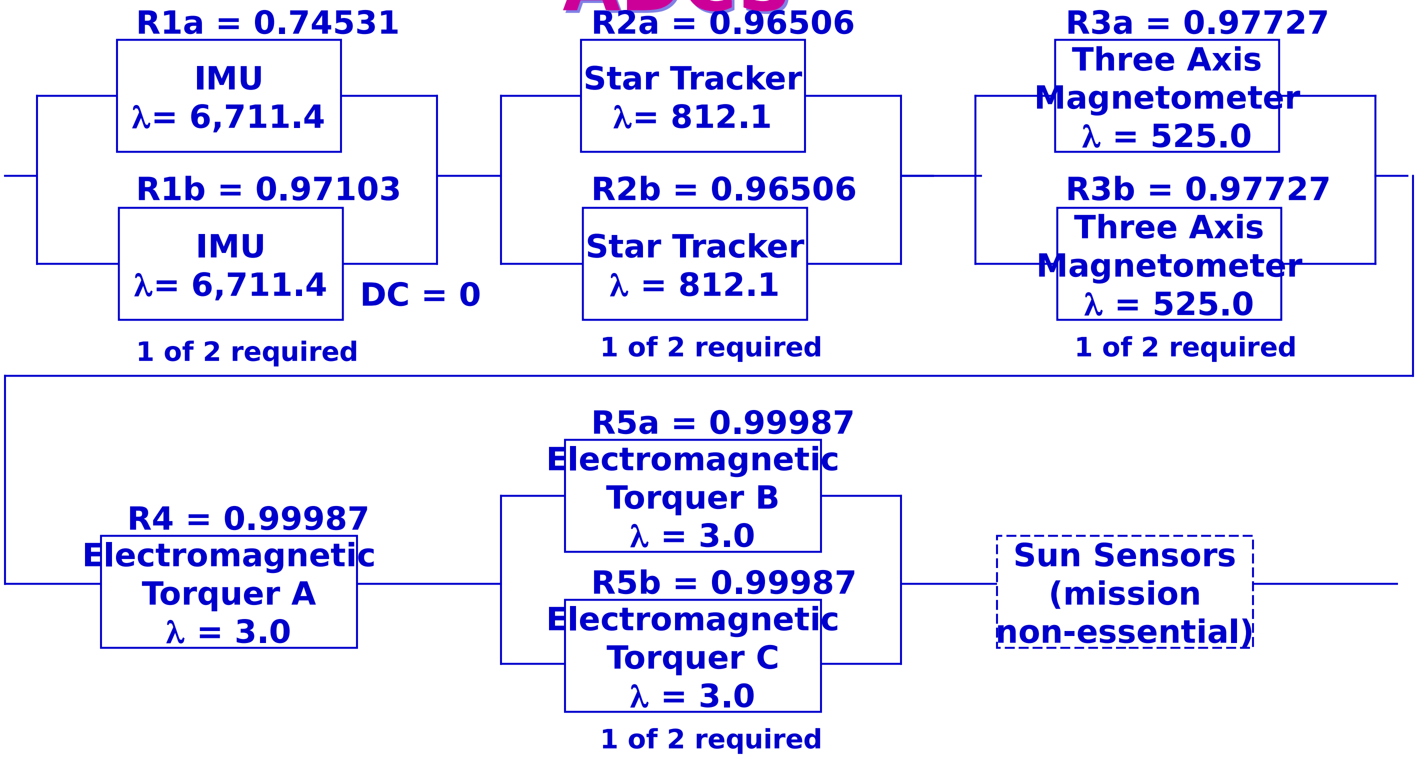
$R_{FAME} = \prod R_i$ for i = 1 to 9

R_1 through R_9 calculations are given in subsequent diagrams.

RELIABILITY PREDICTION

$R_{FAME} = 0.68611$

Reliability Block Diagram - ADCS



MATHEMATICAL MODEL LEGEND

R_{ADCS} = Reliability of the ADCS for 5 Year (43,800 hour) mission.
R_i = Reliability of the i^{th} ADCS subsystem
λi = Failure rate of i^{th} unit in failures per billion hours (FITS).
Tm = Mission time = 43,800 hours
DC = Duty cycle (1.0 unless otherwise noted).
Kd = Standby failure rate multiplier = 0.1

MATHEMATICAL MODEL

R_{ADCS} = R1 X R2 X R3 X R4 X R5
R1 = (R1a)+ (Ln(R1a)/Ln(R1b))*(R1a)(1- (R1b))
R2 = (R2a) + (R2b)X(1-R2a)
R3 = (R3a) + (R3b)X(1-R3a)
R5 = (R5a) + (R5b)X(1-53a)
Ria or ib of the form:
exp[-(λi) X Tm X (DC + Kd(1 - DC))]

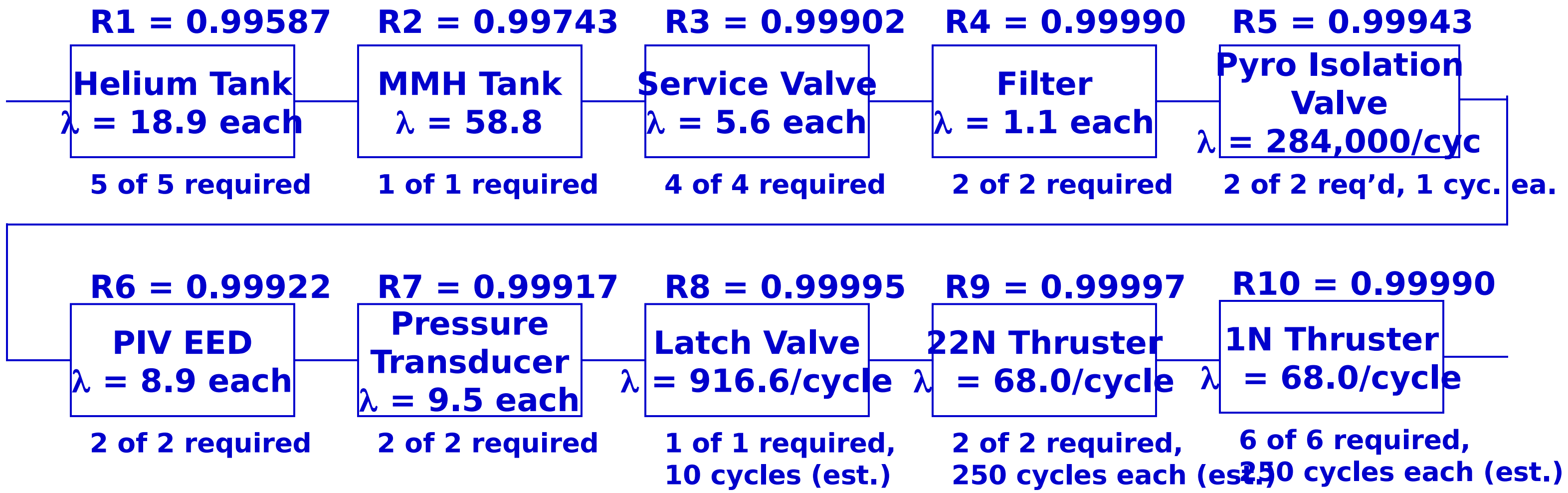
RELIABILITY PREDICTION

R_{ADCS} = 0.95941
R1 = 0.96121
R2 = 0.99878
R3 = 0.99948
R4 = 0.99987
R5 = 0.99999

FAILURE RATE SOURCE

IMU - Vendor Data (Litton)
Star Tracker - Clementine
TAM - TLD
EMT - Vendor Data (ITHACO)

Reliability Block Diagram - RCS



MATHEMATICAL MODEL LEGEND

R_{RCS} = Reliability of the RCS for 5 Year (43,800 hour) mission.
R_i = Reliability of the i^{th} RCS subsystem
λi = Failure rate of i^{th} unit in failures per billion hours (FITS).
Tm = Mission time = 43,800 hours

MATHEMATICAL MODEL

$R_{RCS} = {}_{1}\Pi^{10}\, Ri$

R1, R2, R3, R4, R6, and R7 of the form:
exp[-(λi) X Qty X Tm]
R5, R8, R9, and R10 of the form:
exp[-(λi) X Qty X Cycles]

RELIABILITY PREDICTION

R_{RCS} = 0.98990

FAILURE RATE SOURCE

EED - ICM
All others - Clementine

Reliability Block Diagram - Interstage

R1 = 0.98000

Solid Rocket
Motor with
Redundant
Detonators
λ = 20,202,000/cycle

1 of 1 required,
1 cycle

MATHEMATICAL MODEL LEGEND

$R_{Interstage}$ = Reliability of the Interstage

MATHEMATICAL MODEL

$R_{Interstage}$ = R1

R1 of the form:
exp[-(λ/cycle) X Cycles]

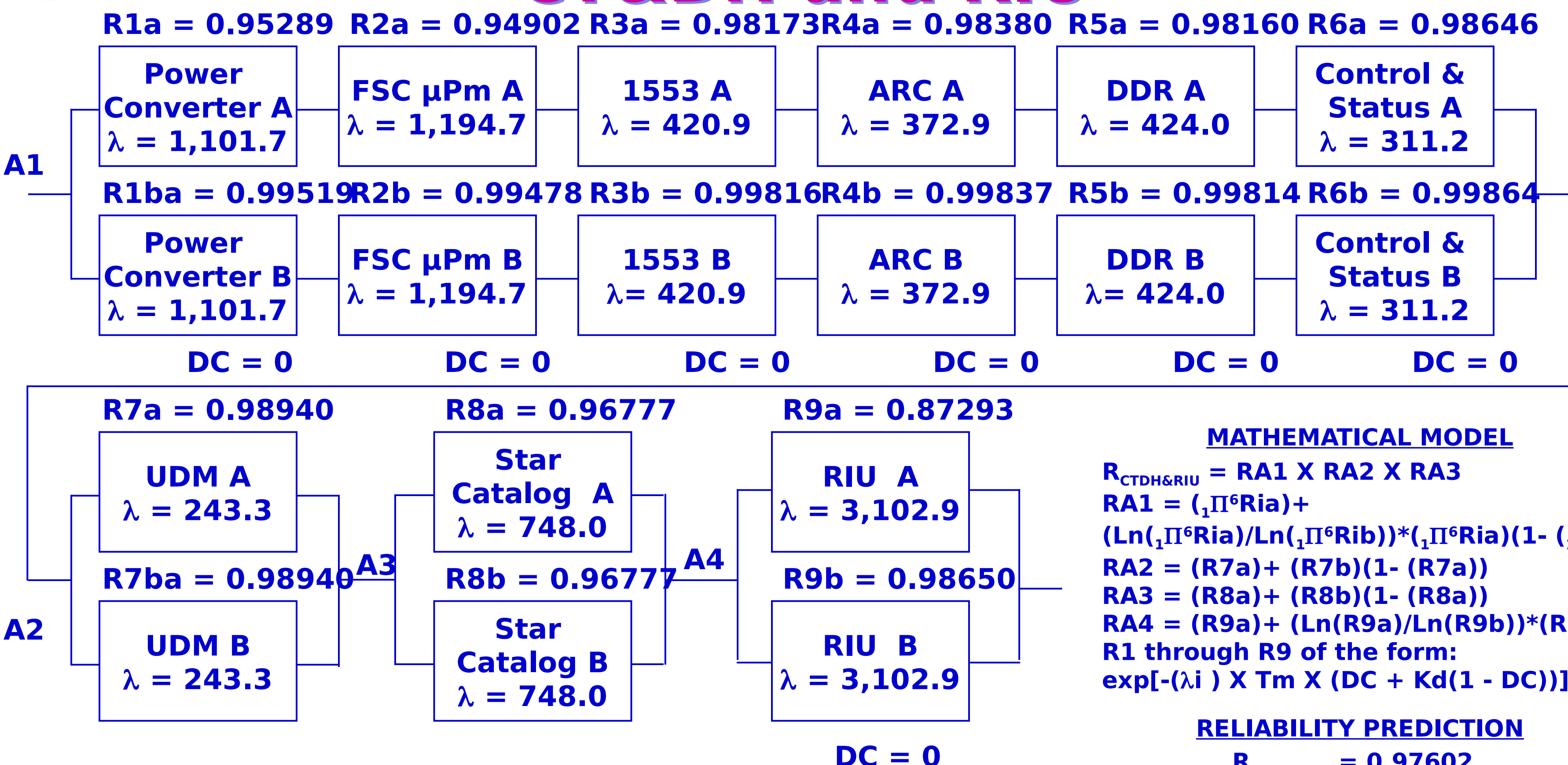
RELIABILITY PREDICTION

$R_{Interstage}$ = 0.98000

FAILURE RATE SOURCE

Clementine Spacecraft

Reliability Block Diagram - CT&DH and RIU



<u>MATHEMATICAL MODEL</u>

$R_{CTDH\&RIU}$ = RA1 X RA2 X RA3

RA1 = ($_1\Pi^6$Ria)+

(Ln($_1\Pi^6$Ria)/Ln($_1\Pi^6$Rib))*($_1\Pi^6$Ria)(1- ($_1\Pi^6$Rib

RA2 = (R7a)+ (R7b)(1- (R7a))

RA3 = (R8a)+ (R8b)(1- (R8a))

RA4 = (R9a)+ (Ln(R9a)/Ln(R9b))*(R9a)(1-

R1 through R9 of the form:

exp[-(λi) X Tm X (DC + Kd(1 - DC))]

<u>RELIABILITY PREDICTION</u>

$R_{CTDH\&RIU}$ = 0.97602

RA1 = 0.98626

RA2 = 0.99989

RA3 = 0.99896

RA4 = 0.99076

<u>MATHEMATICAL MODEL LEGEND</u>

$R_{CTDH\&RIU}$ = Reliability of CT&DH and RIU Subsystems for 5 Year mission.

R_i = Reliability of the i^{th} CT&DH and RIU unit

λi = Failure rate of i^{th} unit in failures per billion hours (FITS).

Tm = Mission time = 43,800 hours

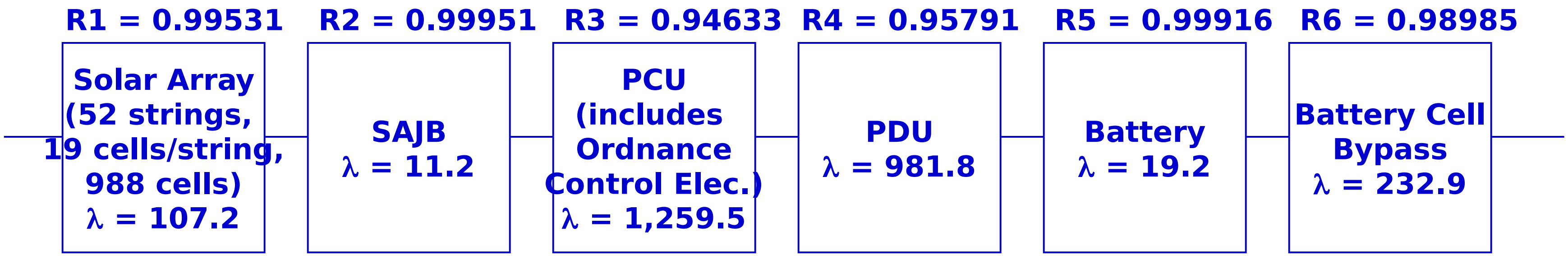
DC = Duty cycle (1.0 unless otherwise noted).

Kd = Standby failure rate multiplier = 0.1

<u>FAILURE RATE SOURCE</u>

217F Parts Count Failure Rate Analysis

Reliability Block Diagram - EPS



MATHEMATICAL MODEL LEGEND

R_{eps} = Reliability of the Electrical Power Subsystem for 5 Year (43,800 hour) mission.
R_i = Reliability of the i^{th} EPS subsystem
λi = Failure rate of ith unit in failures per billion hours (FITS).
Tm = Mission time = 43,800 hours

MATHEMATICAL MODEL

R_{EPS} = R1 X R2 X R3 X R4 X R5 X R6

R1 through R6 of the form:
exp[-(λi) X Tm]

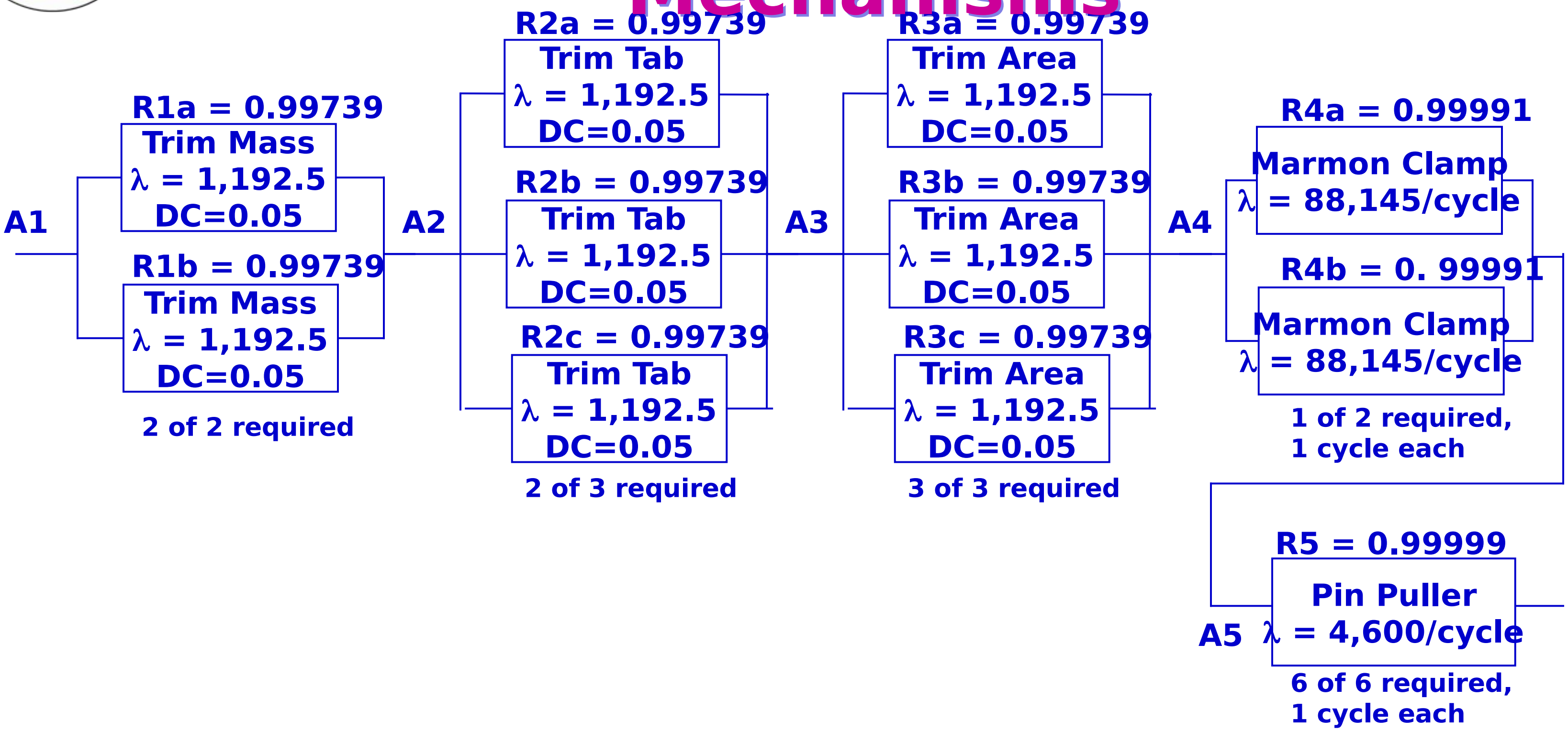
RELIABILITY PREDICTION

R_{EPS} = 0.89190

FAILURE RATE SOURCE

Battery - Clementine
All others - ICM

Reliability Block Diagram - Mechanisms



MATHEMATICAL MODEL LEGEND

R_{MECH} = Reliability of the Mechanism Subsystem for 5 Year (43,800 hour) mission.
R_i = Reliability of the i^{th} Mechanism subsystem
λi = Failure rate of ith unit in failures per billion hours (FITS).
Tm = Mission time = 43,800 hours
DC = Duty cycle (1.0 unless otherwise noted)

MATHEMATICAL MODEL

R_{MECH} = RA1 X RA2 X RA3 X RA4 X RA5
RA1 = (R1a)+ (R1b)(1- (R1a))
RA2 = (R2^3)+ 3X (R2^2)(1-R2)
RA3 = R3a X R3b X R3c
RA4 = (R4a)+ (R4b)(1- (R4a))
RA5 = R5^6
R1 through R3 of the form:
exp[-(λi) X Tm X DC]
R4 and R5 of the form:
exp[-(λi) X Cycles]

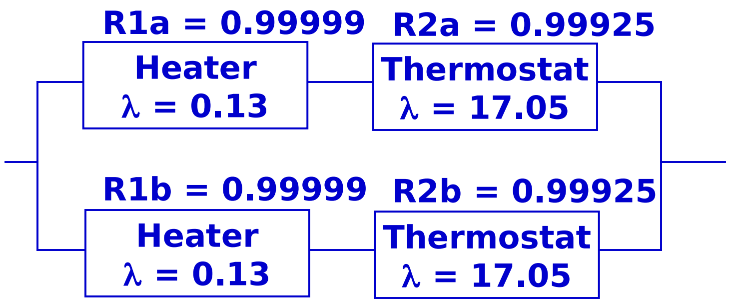
RELIABILITY PREDICTION

R_{MECH} = 0.99213
RA1 = 0.99999
RA2 = 0.99998
RA3 = 0.99220
RA4 = 0.99999
RA5 = 0.99997

FAILURE RATE SOURCE

Trim Mass, Area, and Tabs - 217F for Stepper Motor
Pin Puller - Vendor Data
Marmon Clamp - Clementine

Reliability Block Diagram - Thermal



Applies to:

Star Tracker Heaters	2
Magnetometer Heaters	2
Thruster Valve Heaters	2
Sun Sensor Heaters	2
Trim Area Motor Heaters	2
Trim Tab Motor Heaters	2
AKM Heaters	2
CATBED Heaters	2
RCS Tank Heaters	2
RCS Lines/Comps Heaters	2
Instrument Survival Heaters	2
Spacecraft Survival Heaters	2
Electronics Deck Heaters	3
Total	**27**

MATHEMATICAL MODEL LEGEND

$R_{Thermal}$ = Reliability of the Thermal Subsystem for 5 Year (43,800 hour) mission.
R_i = Reliability of the i^{th} Thermal Subsystem
λi = Failure rate of i^{th} unit in failures per billion hours (FITS).
Tm = Mission time = 43,800 hours

MATHEMATICAL MODEL

$R_{Thermal} = R^{27}$

R = (R1aXR2a)+ (R1bXR2b)X(1- (R1aXR2a))

R1 and R2 of the form: exp[-(λi) X Tm]

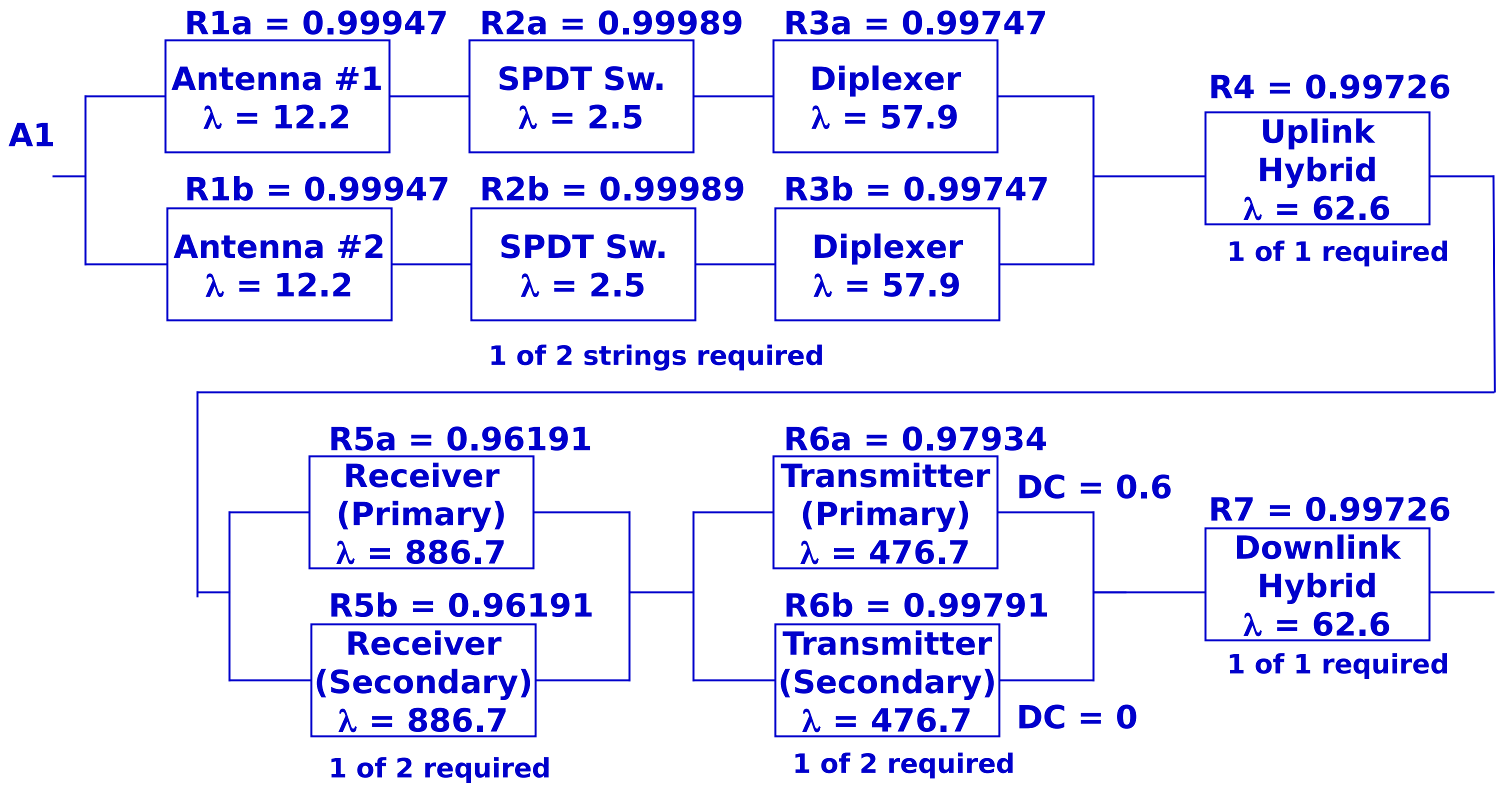
RELIABILITY PREDICTION

$R_{Thermal}$ = 0.99999

FAILURE RATE SOURCE

Heater - ICM
Thermostat - 217F

Reliability Block Diagram - RF Function



MATHEMATICAL MODEL LEGEND

R_{RF} = Reliability of the RF Subsystem for 5 Year (43,800 hour) mission.
R_i = Reliability of the i^{th} RF unit
λi = Failure rate of i^{th} unit in (FITS).
Tm = Mission time = 43,800 hours
DC = Duty cycle (1.0 unless otherwise noted.
Kd = Standby failure rate multiplier = 0.1

MATHEMATICAL MODEL

R_{RF} = RA1 X R4 X R5 X R6 X R7
RA1 = $({}_{1}\Pi^{3}\text{Ria}) + ({}_{1}\Pi^{3}\text{Rib})(1- ({}_{1}\Pi^{3}\text{Ria}))$
R5 = R5a + R5b X (1-R5a)
R6 = (R6a)+ (Ln(R6a)/Ln(R6b))*(R6a)(1- (R6b))
R1 through R7 of the form:
exp[-(λi) X Tm X (DC+Kd(1-DC))]

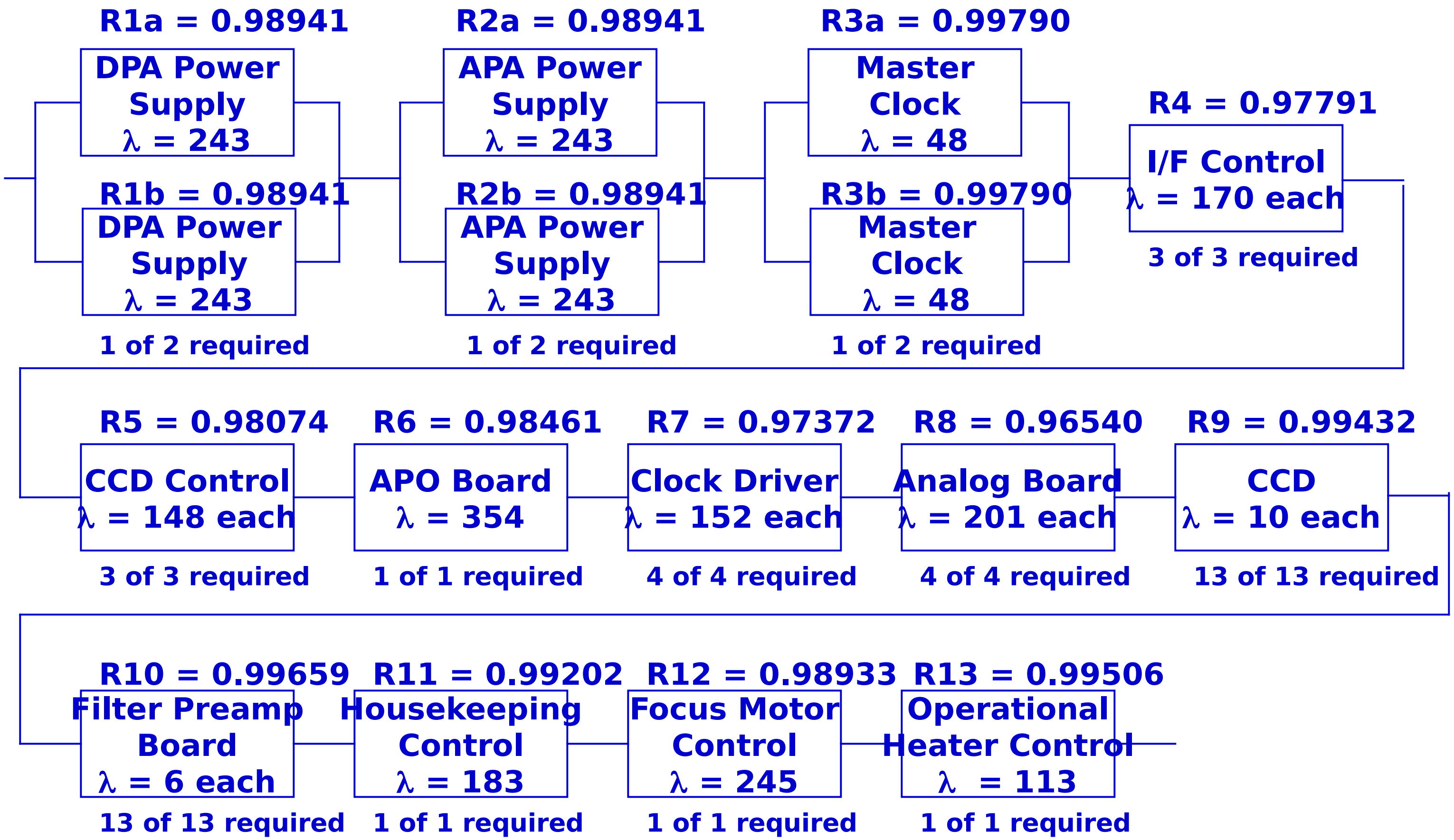
RELIABILITY PREDICTION

R_{RF} = 0.99385
RA1 = 0.99999
R5 = 0.99957
R6 = 0.99976

FAILURE RATE SOURCE

DSPSE Spacecraft

Reliability Block Diagram - Instrument



MATHEMATICAL MODEL LEGEND

$R_{Instrument}$ = Reliability of the Instrument for 5 Year (43,800 hour) mission.

R_i = Reliability of the i^{th} Instrument

λi = Failure rate of i^{th} unit in failures per billion hours (FITS).

Tm = Mission time = 43,800 hours

MATHEMATICAL MODEL

$R_{Instrument}$ = R1 X R2 X R3 X Rstring

R1 = R1a + R1b X (1-R1a)

R2 = R2a + R2b X (1-R2a)

R3 = R3a + R3b X (1-R3a)

RString = $\exp[-({}_4\Sigma^{13}\ \lambda i\ ) \times Tm]$

R1 through R13 of the form: $\exp[-(\lambda i\ ) \times Tm]$

RELIABILITY PREDICTION

$R_{Instrument}$ = 0.85884

R1 = 0.99989

R2 = 0.99989

R3 = 0.99999

RString = 0.85904

FAILURE RATE SOURCE

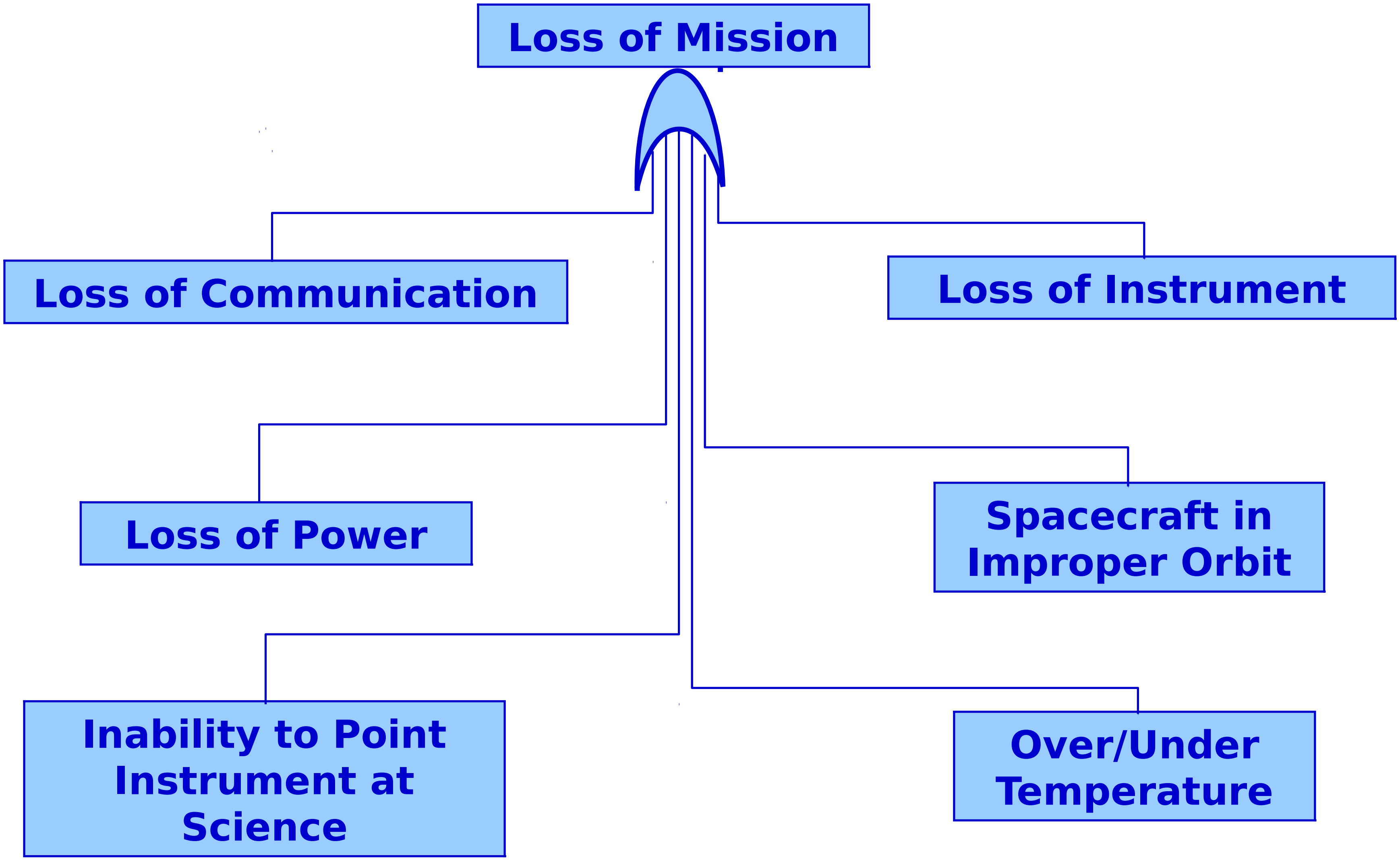
Lockheed Martin Data

FAME Fault Tree Analysis

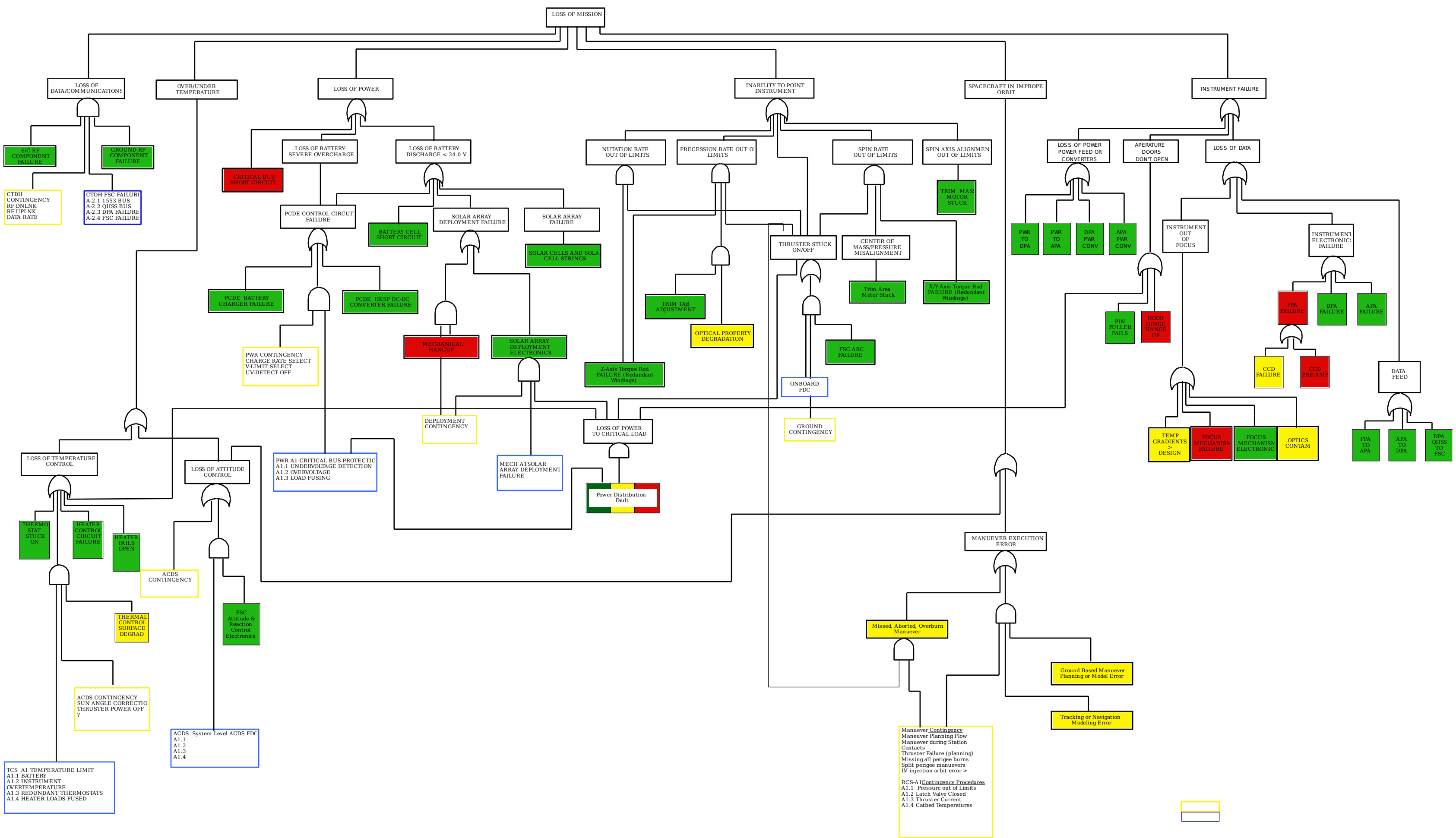
- Fault Tree Starts With “Loss of Mission” As the Top Block
  - Key Is Understanding What Defines “Loss of Mission”
  - Understand the Design of the System and How It Will Be Operated
  - Postulate Faults That Could Result in Loss of Mission
- Faults Are Logically Combined and Further Decomposed Until Lowest Desired Level Is Reached
- Lowest Level Should Overlap and Be Consistent With the FMEA. Typically the Component Major Function Level
- Requirements for Contingency Procedure and Onboard Fault Detection and Correction Should Be Included to Show Where Action Is Required..
- The Fault Tree Provides a Graphical Format for Organizing Postulated Failures, Understanding Their Consequences on the System, and Understanding Their Relationship to Other Systems and Subsystems

Failure Propagation	Redundancy Failures
Single Point Failures	Ground Contingency Procedure
Graceful Failures	Onboard Fault Detection & Control

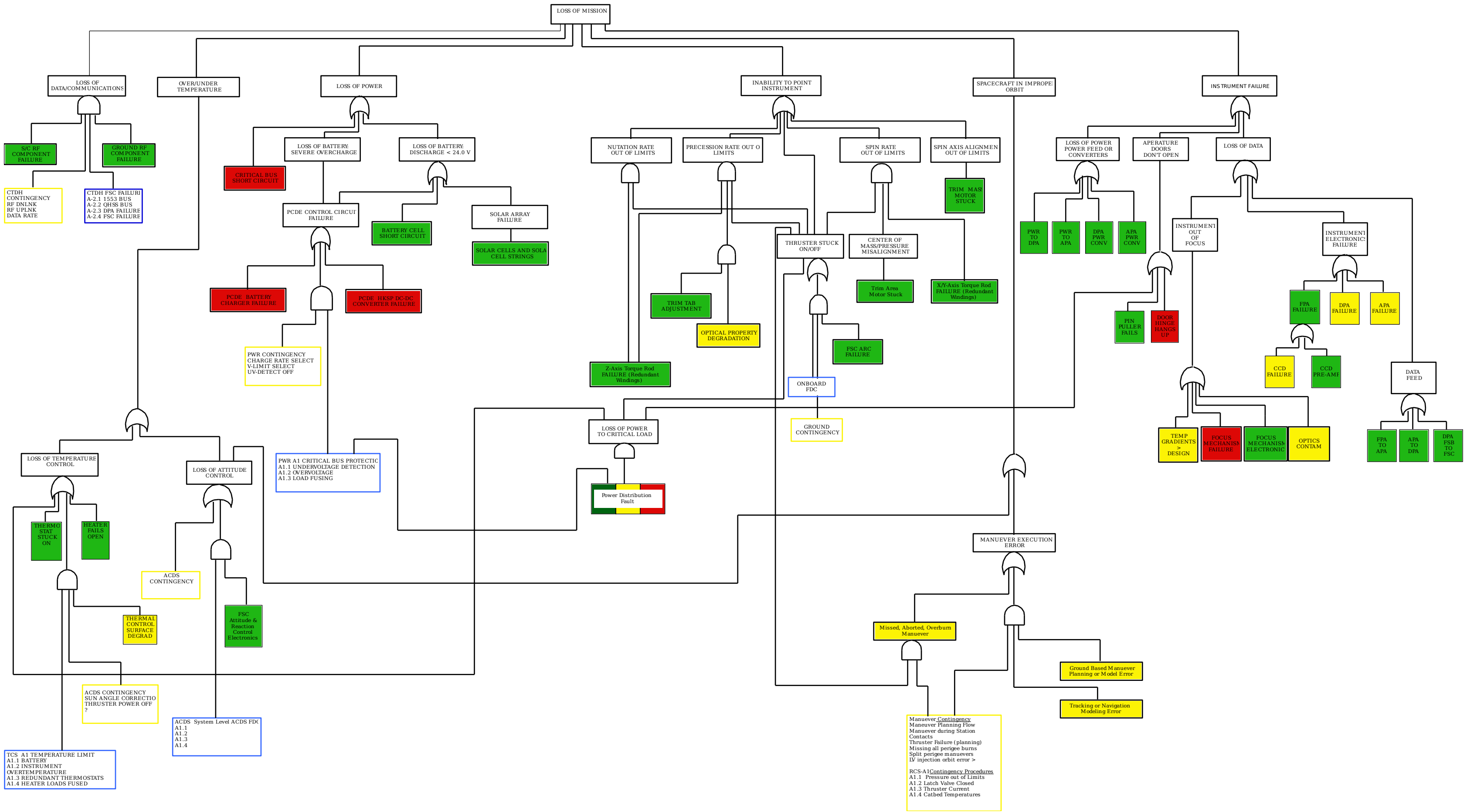
FAME FTA - Loss of Mission



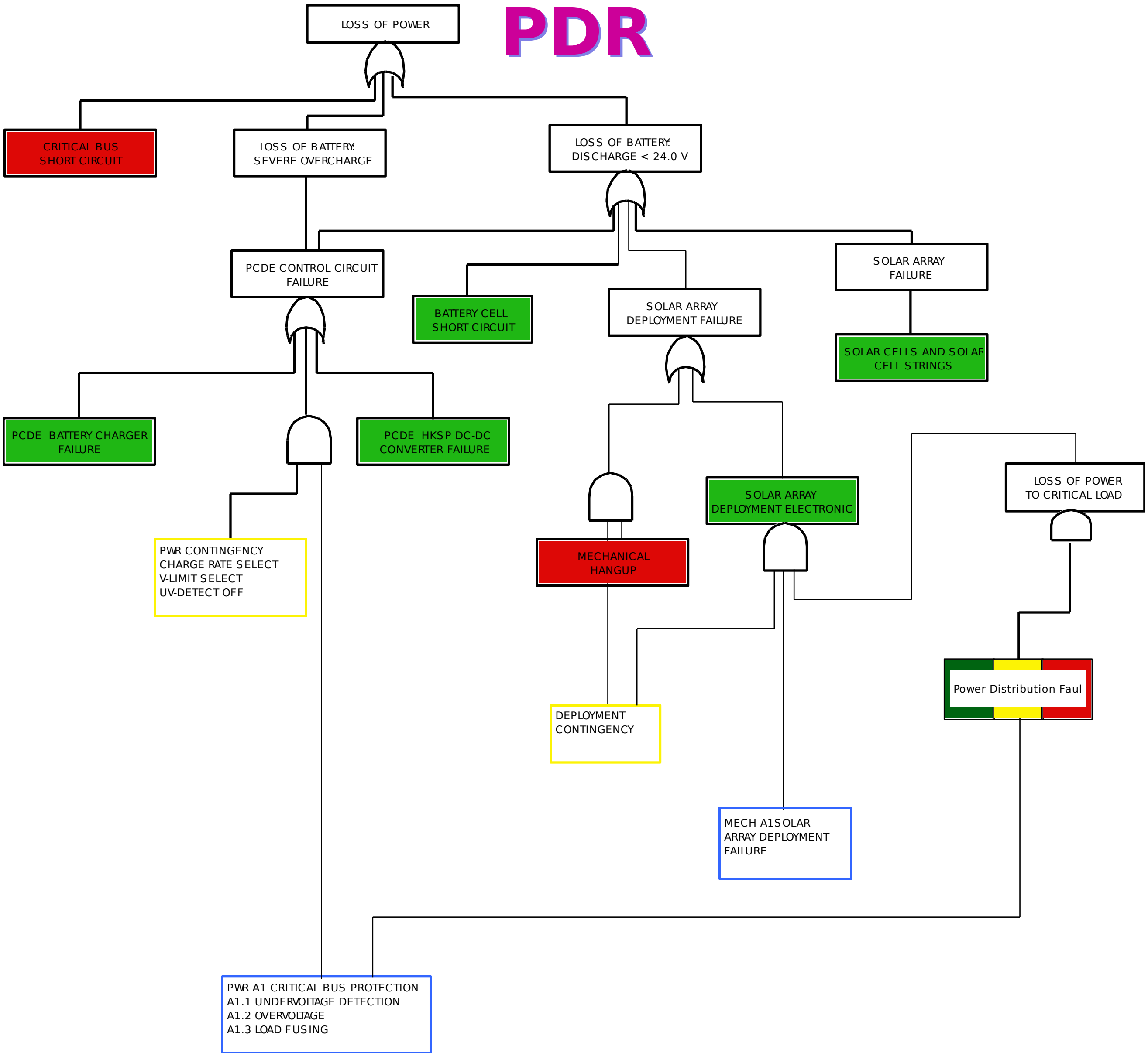
FAME System Fault Tree @ Instrument PDR



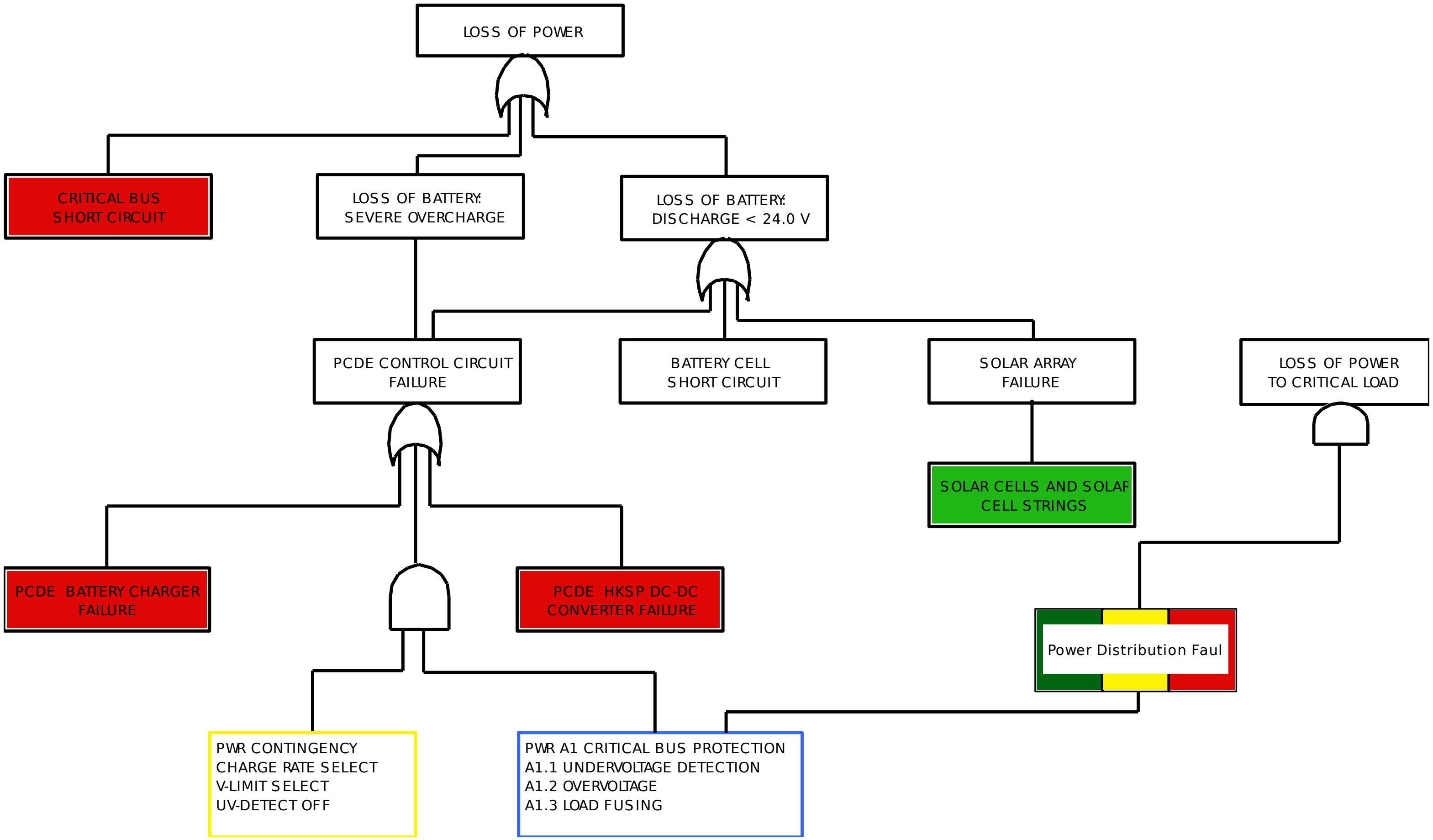
FAME System Level Fault Tree



FAME FTA
Loss of Power at Instrument PDR



FAME FTA
Loss of Power (Present Design)



FAME Failure Modes & Effects Analysis

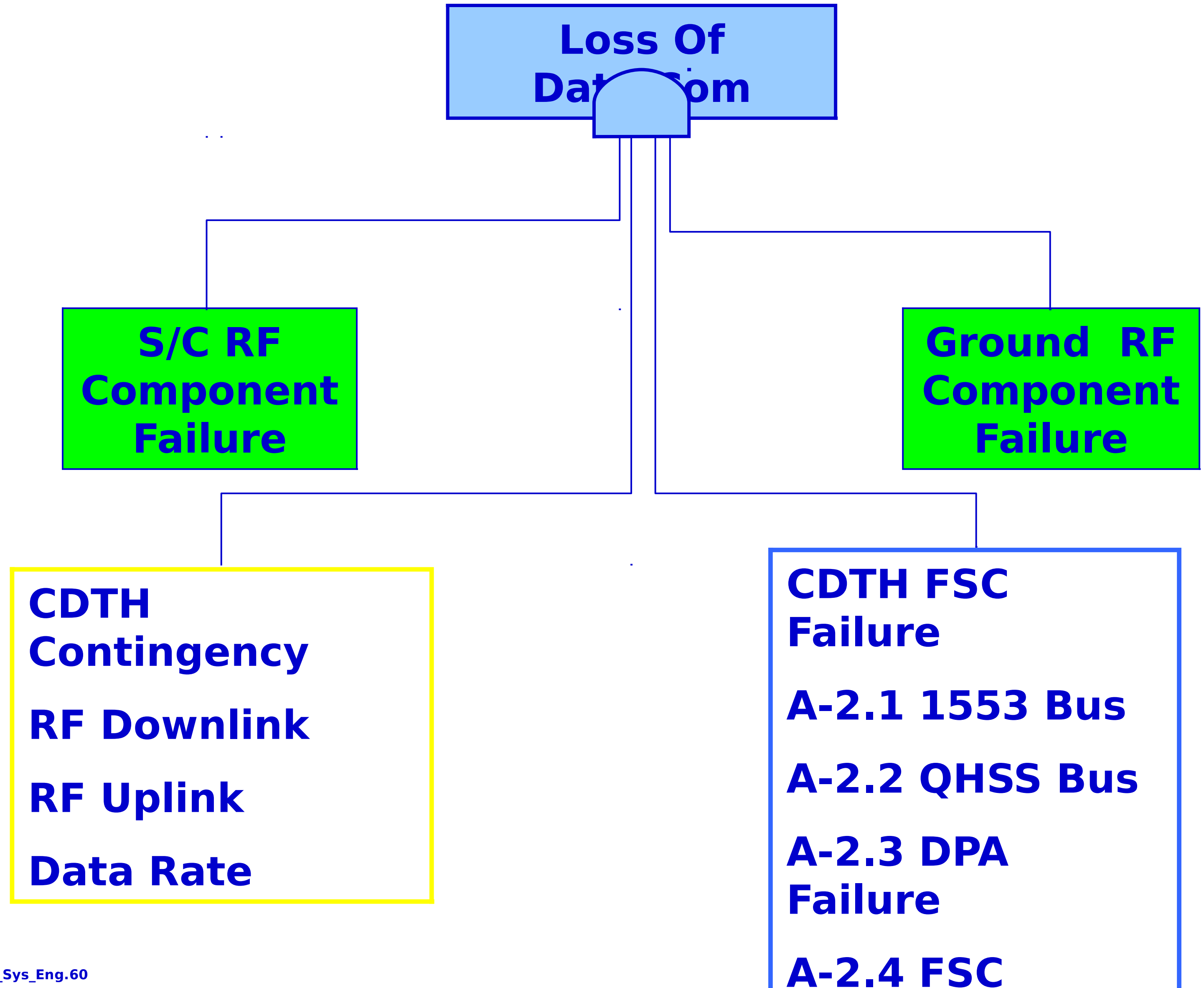
- Initial FMEA's Will Examine S/C Bus to Instrument Interfaces
  - Subsequent FMEA's Will Examine Critical Observatory Interfaces
- Failure Modes Are Identified and Their Failure Effects Classified According to Their Severity or Affect on the S/C Bus, instrument and Mission
  - Category I
    - Total/Major Loss of Observatory
      - Loss of Critical Power Bus
  - Category II
    - Loss of Redundancy Within the S/C Bus or the FAME Instrument
      - Loss of 30V DPA/APA A Power
  - Category III
    - Acceptable, But Degraded Production of Data of Partial Loss of Redundancy
      - Loss of 1 of 13 CCDs
  - Category IV
    - Failure is Not Sufficiently Serious to Affect Data or Redundancy

FAME FMEA Worksheet

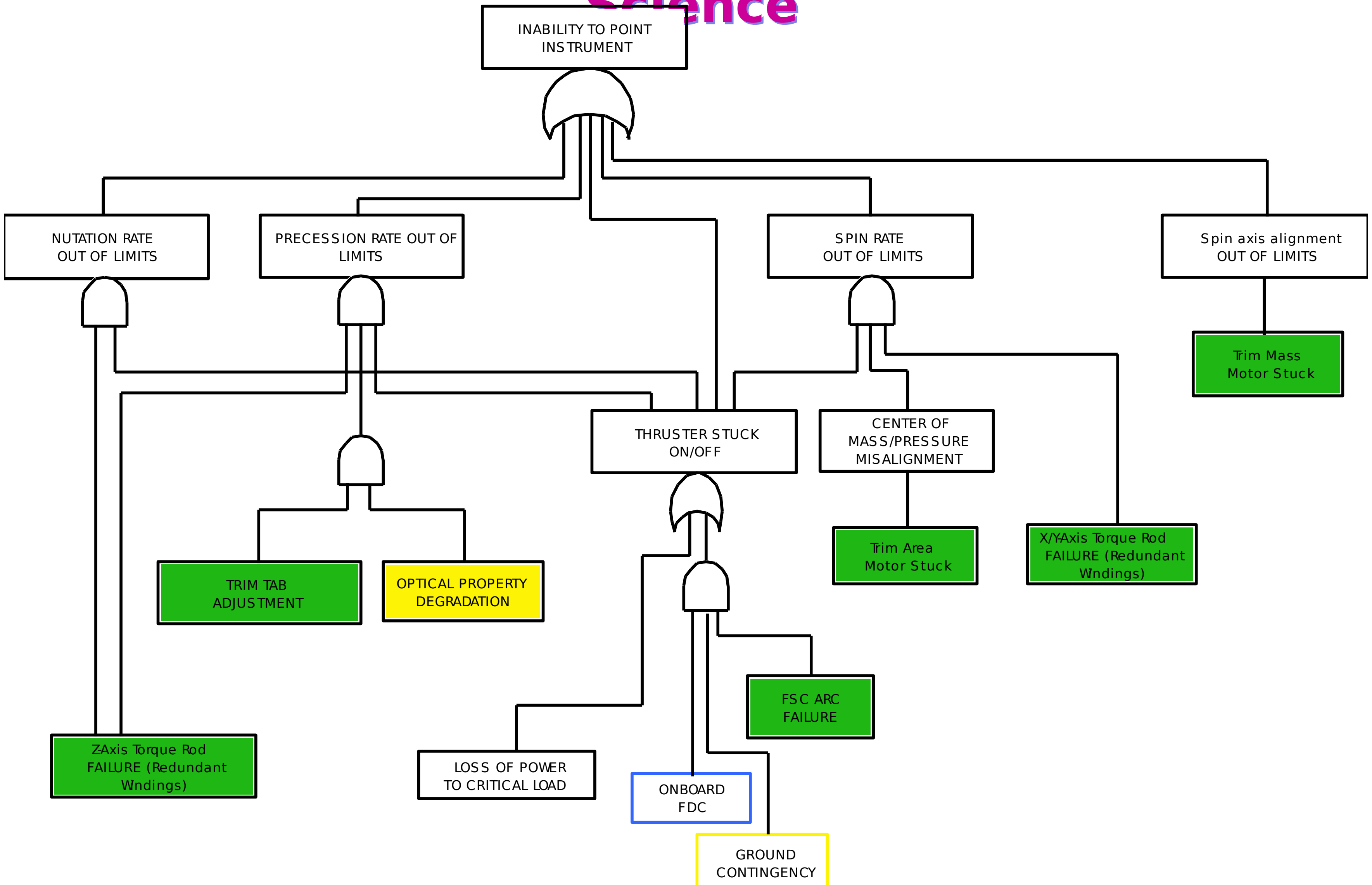
Item	Failure Mode	Local Effects	System Effect	Criticallу
PDU to DPA Power Feed	DPA DC-DC Converter Short to Ground	Open Fuse In PDU	Loss of Redundancy	II
PDU to ADA Power Feed	APA DC-DC Converter Short to Ground	Open Fuse In PDU	Loss of Redundancy	II
PDU to Instrument Survival Heater	Heater Short to Ground	Open Fuse In PDU	Loss of Redundant FSC	II
FSC to Aperature Door 1/2 A Paraffin Actuator	Heater Short to Ground	Open Fuse In PDU	Loss of Redundant FSC	II
FSC to Aperature Door 1/2 B Paraffin Actuator	Heater Short to Ground	Open Fuse In PDU	Loss of Redundant FSC	II
FSC to Instrument CCD Control Clock Line	Line Short to Ground	Loss of Data Channel	Loss of 6 CCD Data	II
FSC to Instrument Serial Command Line	Line Short to Ground	Loss of Cmd Line	Loss of Redundancy	II
RIU to Instrument	Line Short to Ground	Loss of Cmd	Loss of	II

Systems Reliability Backup

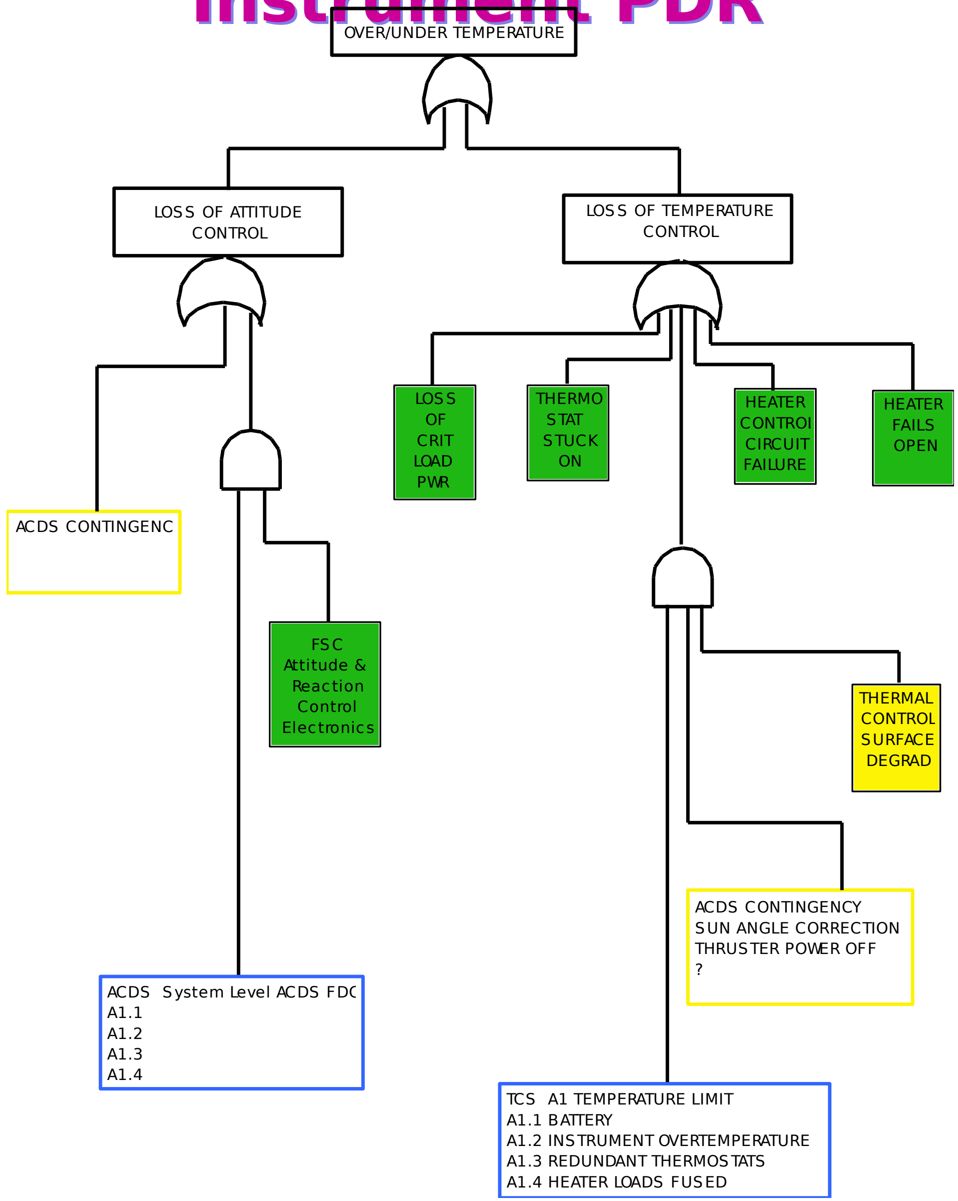
FAME FTA-Loss of Comm



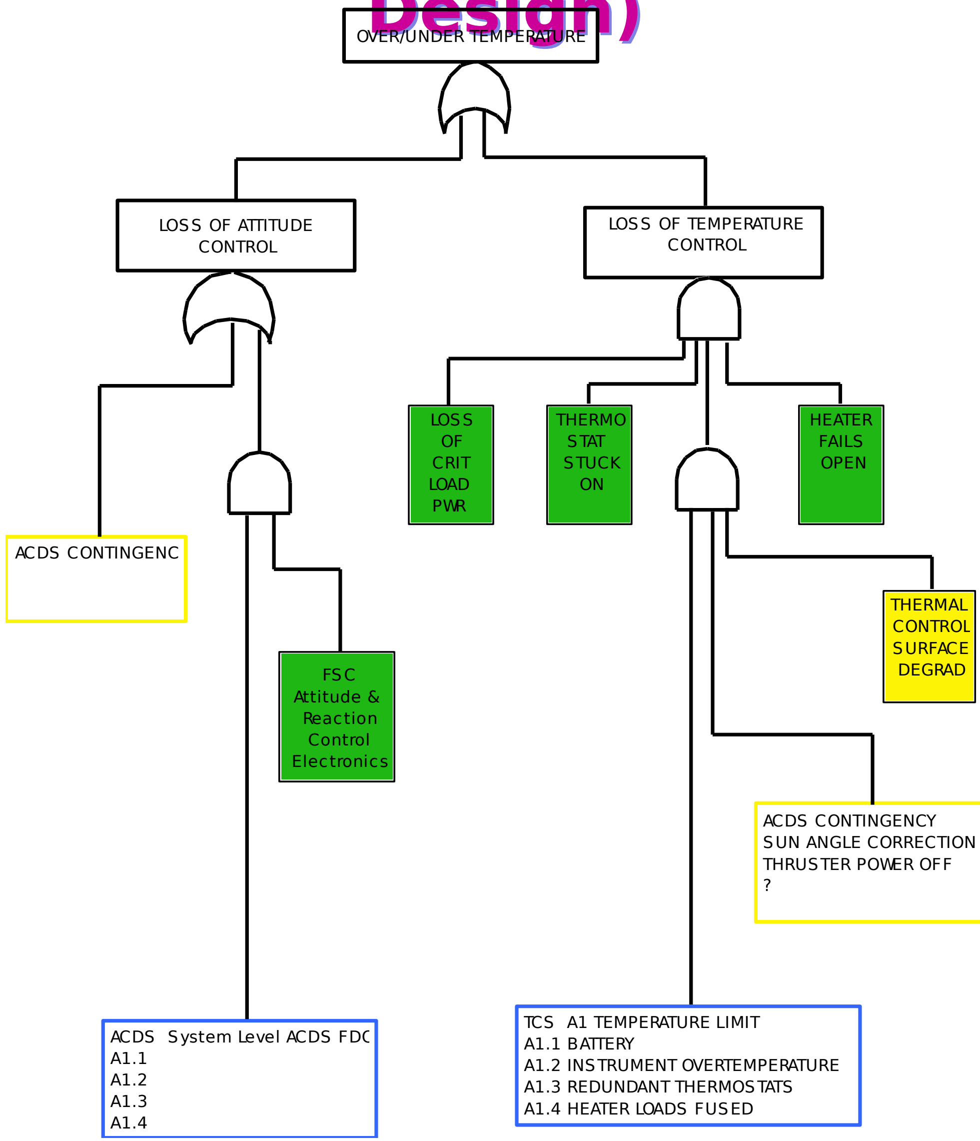
FAME FTA
Inability to Point Instrument At Science



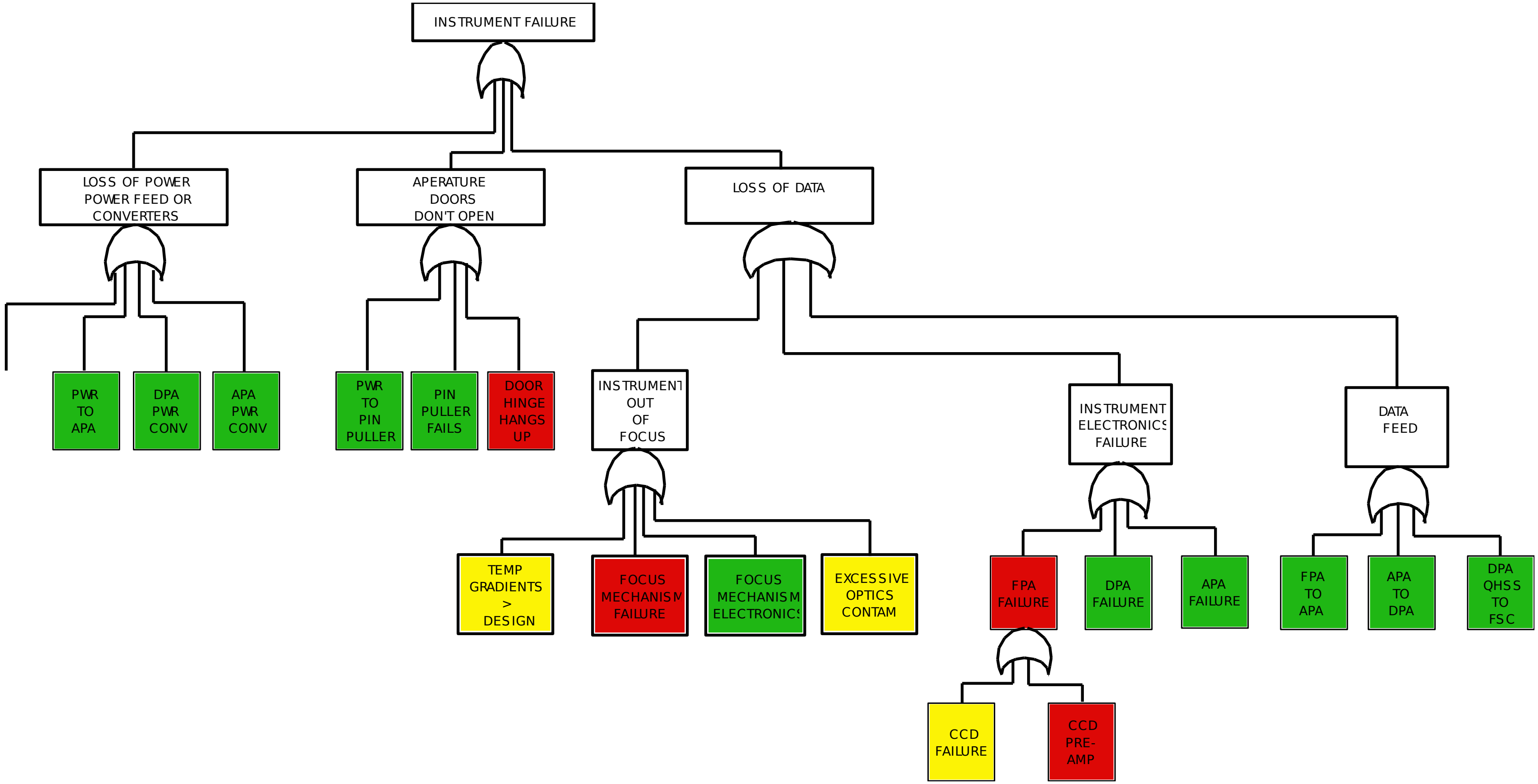
FAME FTA
Over/Under Temperature at Instrument PDR



FAME FTA
Over/Under Temperature (Present Design)



FAME FTA
Loss of Instrument at Instrument PDR



FAME FTA
Loss of Instrument (Present Design)